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Experimental Study of High-Speed Boats with Suspended Flaps for Reducing the Slamming Forces

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Experimental Study of High-Speed Boats with Suspended Flaps for Reducing the Slamming Forces

by

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Most of all, I am extremely thankful to my beloved family, my parents and in laws.

Contents

List of Tables

List of Figure

Nomenclature

x	Horizontal coordinate in Earth-Fixed system aligned with direction of travel	m
y	Horizontal coordinate in Earth-Fixed system, perpendicular with direction of travel	m
z	Vertical coordinate in Earth-Fixed system, position up positive	m
θ	Pitch angle positive bow up	degree
ϕ	Roll angle positive rolling to the right	degree
ψ	Yaw angle measured clockwise from North	degree
θ_1	Sponson1 deflection angle positive when the transom deflect upwards	degree
θ_2	Sponson2 deflection angle positive when the transom deflect upwards	degree
θ_3	Sponson3 deflection angle positive when the transom deflect upwards	degree
θ_4	Sponson4 deflection angle positive when the transom deflect upwards	degree
u_1	Time derivation of x	m/s
u_2	Time derivation of y	m/s
u_3	Time derivation of z	m/s
u_4	Time derivation of θ	Rad/s
u_5	Time derivation of ϕ	Rad/s
u_8	Time derivation of θ_2	Rad/s
u_9	Time derivation of θ_3	Rad/s
u_{10}	Time derivation of θ_4	Rad/s
M	Mass of center of hull	Kg
m1	Mass of right front sponson	Kg
m3	Mass of right rear sponson	kg

m4	Mass of left rear sponson	kg
g	Gravitational acceleration	m/s^2
k	Spring stiffness	N/m
C	Damping coefficient	Ns/m
a1	Distance between transoms of front sponsons	m
a2	Distance between transoms of front sponsons	m
a3	Distance between transoms of rear sponsons	m
a4	Distance between transoms of rear sponsons	m
a5	Distance between transoms of front sponsons	m
a6	Distance between transoms of front sponsons	m
a7	Distance between transoms of rear sponsons	m
a8	Distance between transoms of rear sponsons	m
a9	Distance between transoms of front sponsons	m
a10	Distance between transoms of front sponsons	m
a11	Distance between transoms of rear sponsons	m
a12	Distance between transoms of rear sponsons	m
a13	Distance between transoms of front sponsons	m
a14	Distance between transoms of rear sponsons	m
a15	Distance between transoms of front sponsons	m
a16	Distance between transoms of rear sponsons	m
I	Moment of inertia of center of hull	Ns/m
Is	Moment of inertia of sponsons	Ns/m
F	External Force vector	N

FI	Inertial Force vector	N

Abstract

This thesis consists of two parts. In the first part a small-scale high-speed monohull boat was fitted with a suspended flap under the bottom. The author tested shock absorbers for this boat, and worked on data analysis from a few initial test runs. The boat tests were performed during a few hours in a single day and the data are far too scarce to draw any conclusions. The second part of the thesis concerns multi-body numerical analysis of a suspension boat that consists of an airborne centerhull and four suspended sponsons.

No simulations of boat dynamics in waves were performed.

First, a brief overview of slamming problem and techniques used to reduce the vertical acceleration was conducted, full description of proposed mechanism and the instruments used to evaluate the boat behavior equipped with the mechanism, then boat testing and data analysis was illustrated.

Second, advanced dynamic numerical model for the suspension boat with four sposons was developed.

1 Introduction

1.1 Slamming Definition

Slamming is defined as a violent impact event between a fluid and the hull surface of a watercraft. This type of fluid/solid interaction typically occurs in rough weather with steep waves [1]. As the watercraft speed and wave height increases, the maximum vertical accelerations can increase from 2 to 7 g's through regions described as uncomfortable, extreme discomfort, to eventual pain and possible injury [2][3].

The slamming phenomenon is a major consideration in the operation and design of high-speed marine vessels. Slamming loads are dependent on the sea conditions, vessel speed, wave encounter direction and the geometry and structural characteristics of the hull .

1.2 Slamming Effects on High-Speed Boats

High-speed - planing hulls are commonly used by naval vessels, for various types of high-speed boat configurations, depending on the mission requirements. The military and commercial boating industry have long known of the potential for acute injury to personnel operating high-speed boats in relatively rough seas. Even low-speed operations of these boats, in certain instances, can result in serious injury due to the violent way the boats can respond to the seas under slamming conditions.

A comparison between hospitalization rates for the navy as a whole and the SWCC (Special Warfare Combat Crewmen), SBUs (Special Boat Units) community was made, in order to further support a connection between mechanical shock exposure on increased occurrence of acute and chronic injuries. Fig (1-1) shows a graphic representation of these hospitalization rates .

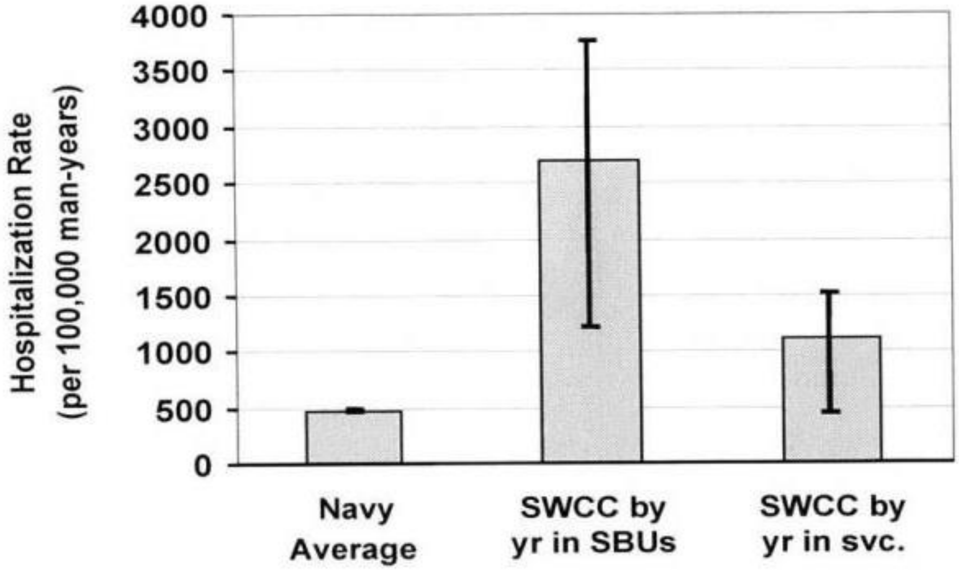


Figure 1-1Comparison of Hospitalization Rates (from [5])

The comparison shown in Fig (1-1) seems to clearly indicate a correlation between SWCC service

and increased rates of injury requiring hospitalization.

Another survey on special boat units' injuries was done by the Naval Health Research center and concluded that Special Boat Units personnel are at greater than average risk of injury.

Methods to reduce equipment and medical costs due to mechanical shock loading has become a vital goal for the U.S. Navy and the boating industry.

1.3 Alternative Approaches Used to Reduce the Slamming Impact

The methods of mitigating mechanical shock effects on high-speed boats can be broken down into two categories: (1) hydrodynamic-mechanical, and (2) electro-mechanical systems, designed to reduce or distribute the shock. A summary of the various methods and locations where shock reduction can be applied is shown in Fig (1-2).

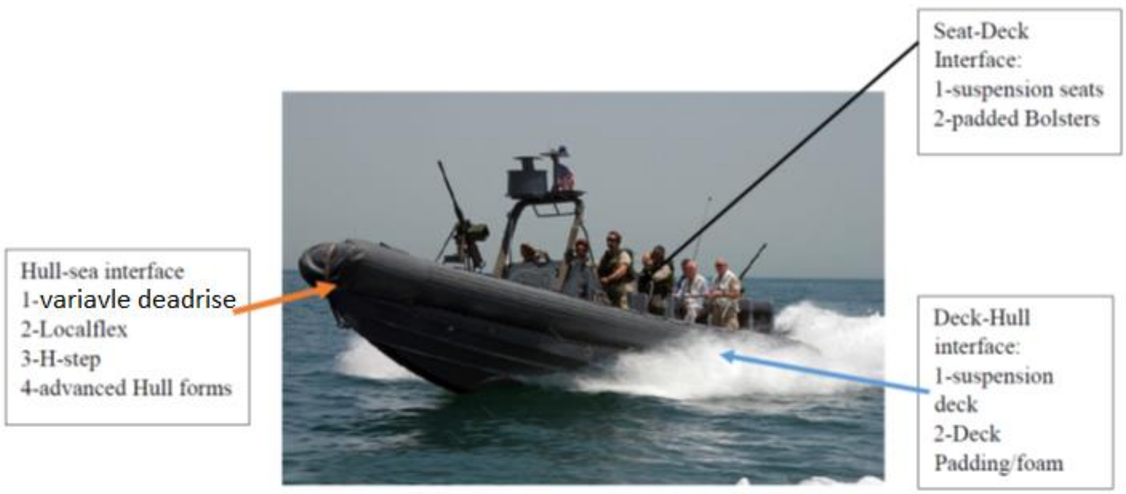


Figure 1-2Methods and Locations for the Application of Shock Reduction Systems ([4]).

Hull-Sea Interface

The logical way to reduce the effects of mechanical shock on high-speed boats is to do it before the external shocks enter the boat structure at all. There are several shock mitigations concepts and technologies that seek to accomplish just that.

The effects of weaker shock events may then be further reduced during transmission by using deck-hull, or seat-deck mitigation systems; this is by far the most difficult, time consuming,

and expensive solution .

Optimal Deadrise Hull

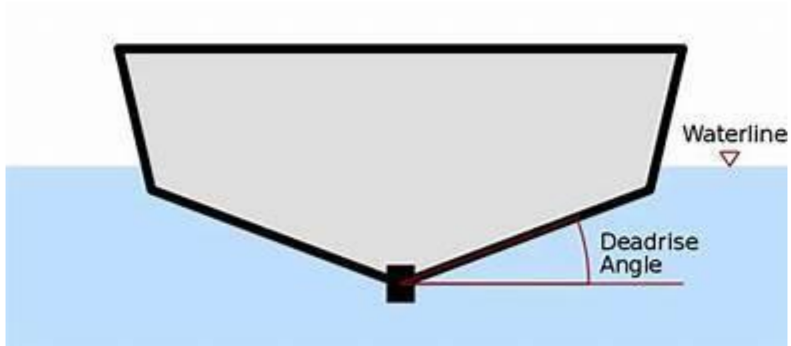


Figure 1-3Deadrise Angle

The angle a boat's hull makes with the horizontal plane is commonly called deadrise shown in Fig (1-3).

One such concept is Optimal Deadrise Hull (ODH) design. ODH seeks to find the

most favorable set of deadrise angles for a hull design, to allow for desired speed performance

while still reducing the magnitude of mechanical shock pulses from seaway interactions.

Based on initial research, changes of as little as 3 degrees in hull deadrise can result in

shock reductions of 12% or more, with no appreciable change in boat hull resistance.

Local-Flex

Local Flex is a system created by Vorus at the University of New Orleans .

It is an external hull attachment that can be configured for existing hull shapes and consists of aluminum plates hinged at the keel, supported by air bags at the chines, as shown in Fig (1-4).

LocalFlex is effective in reducing the level of impact acceleration.

The dynamic measurements were obtained with the use of the drop test model and two high bandwidth triaxial piezo-resistive accelerometer sets. All drops were performed in the drop Test

Pool using an overhead crane and quick-release mechanism.

Significant reductions are observed, e.g., shock reductions of up to 45% were

obtained. However, the prototype system had no capability to "recover" to its original

vee shape in preparation for successive impacts. While an engineering

solution can potentially be found for this lack of recoverability, such a solution would

likely add unwanted weight and complexity to the design .

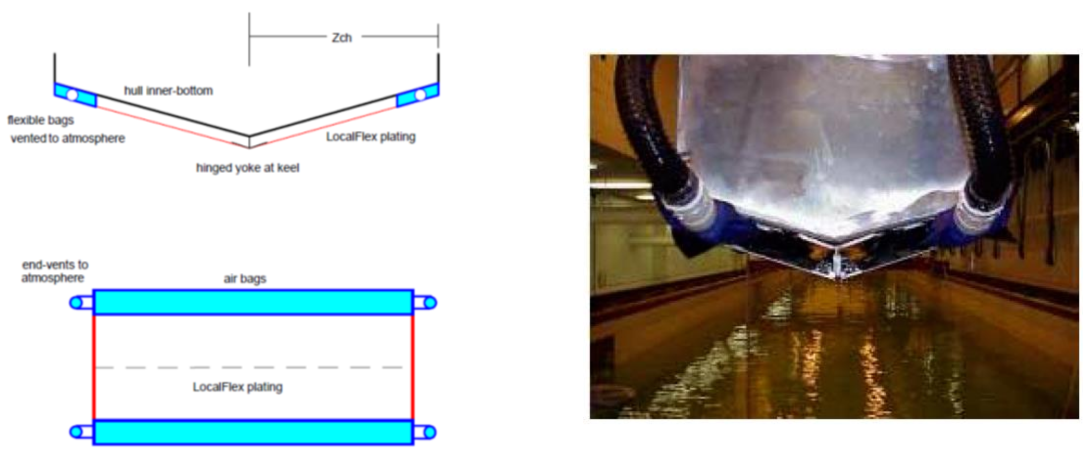


Figure 1-4 Local Flex [9]

Advanced Hull Forms

Research and development of advanced hull forms is a continuous process to reduce violent wave-hull interactions. forms such as hydrofoils and air cushions have long been used in watercraft to obtain high speeds with minimal interaction with the water surface. However, due to their limited range and payload capacities, lack of covertness, and relatively intensive maintenance and upkeep requirements, these types of vessels are not well suited for special warfare use. Other hull shapes, such as catamarans, very slender vessels, and small waterplane area craft, could potentially provide the performance needed by the special warfare community, while minimizing seaway interactions and the accompanying mechanical shocks. Continuing development of these and another advanced hull is still ongoing. Fig (1-5) shows a summary of various hull forms in use.

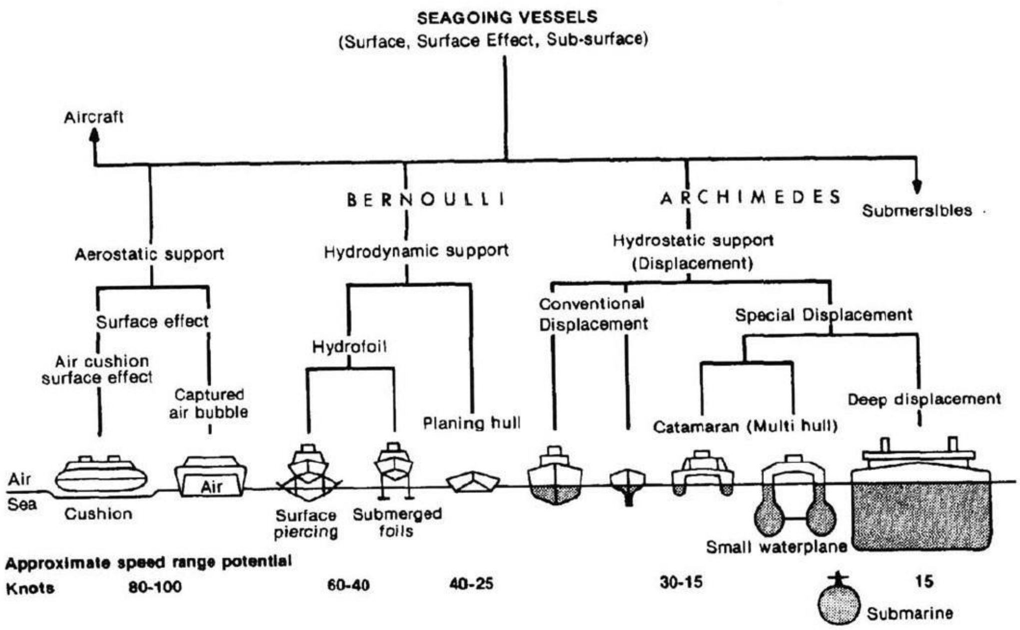


Figure 1-5 Various Hull (Forms [5])

Deck-Hull Interface

Rubber or foam padding (or similar cushioning material) are the most common damping materials used to reduce and absorb shock and vibration at the deck-hull interface.

Due to the limited space available in many small high-speed boats, their ability to significantly reduce shock loading is limited.

Suspension Seats

Suspension seats can be effective in order to reduce the vibration levels transmitted to the human body, several studies regarding improved seat solutions have been published .

One of the most effective solutions for isolating occupants on high-speed craft that are currently in service is to implement shock mitigating seats. There are three types of shock isolation systems that can be implemented. The first is the passive isolation system, which is the most commonly used of these systems, where the damping coefficient of the damper does not automatically adjust for varying environmental conditions.

The second most commonly used system implemented is the semi-active suspension system. The semi-active suspension also incorporates a spring and damper system just as the passive system.

The damping coefficient of the damper changes in real time to accommodate for changes in the environment. The system incorporates a control scheme which uses sensors that read environment conditions to change the damping characteristics to best dissipate energy. The damping characteristics are changed by controlling the fluid valves within the shock assembly.

The third suspension system is the fully active or active system. This is most effective and complex system since, and independent force can exert to control motion. In an independent force in the required direction to limit motion. Hydraulic, magnetic or electric actuators are used for force exertion. The addition of an actuator allows designers to completely control the dynamics of the suspension system. External sensors are used to determine environment conditions and focus is placed onto determining the environment ahead to allow the actuator to prepare the system for future outside input.

An active suspension is rarely implemented due to the complex nature and high-power requirements.

Fig (1-6) show a fully active shock mitigating seat with various suspension components.

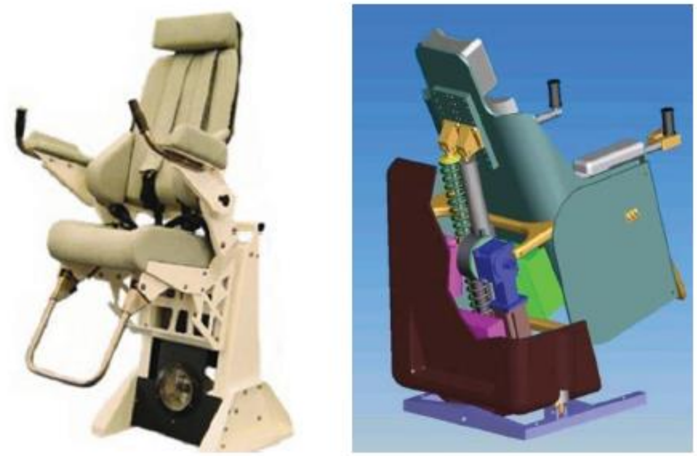


Figure 1-6 Fully active shock mitigating seat [11]

1.3.1 Suspension Boat

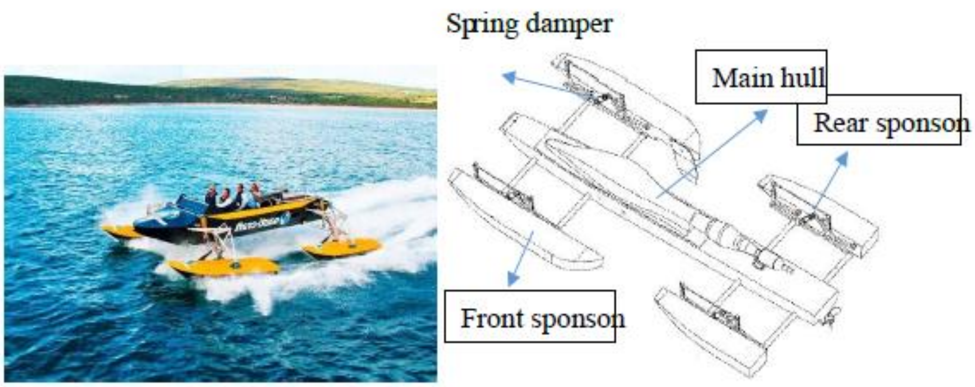


Figure 1-7 Boat Hull Linked to Front and Rear Sponsons Through a Suspension System [12].

New method to reduce vertical accelerations have been invented, developed and tested on scaled models . The concept of new approach consisting of some running surfaces, or sponsons, attached through suspension to center-hull as shown in Fig (1-7).

Numerous model testes have been performed, operated at speed above 33 m/s (64 knots) in various sea states. All of them have two or more sponsons that contact the water and that are attached via suspension links, springs and dampers to center of hull.

Tests with small scale suspension boat running side by side with boats of same size and at the same speeds but with conventional hull forms indicate that vertical accelerations may be reduced approximately an order of magnitudes in these suspension boats.

The Nauti-Craft company applied a suspension system that improves the ability of a vessel to maintain a good speed in rough sea states.

The interconnected suspension system is designed such that it operates substantially passively and the stiffness and damping of some or each of the roll, pitch heave and warp modes can be individually tuned. Being able to provides the designer with many options to optimize performance. The systems proposed operate passively when under way, or when on a mooring or when driven against a structure such that the superstructure and deck remain more stable than the deck of any conventional vessel. Fig (1-8) demonstrates the motion reduction provided by the Nauti-Craft Quad prototype over a Conventional Monohull. It shows the highest and lowest point of both vessels over a 30 second period. The displacement is reduced by a factor of approximately 5 by the Nauti-Craft suspension system, despite the weights and lengths of the crafts being within approximately 20%.

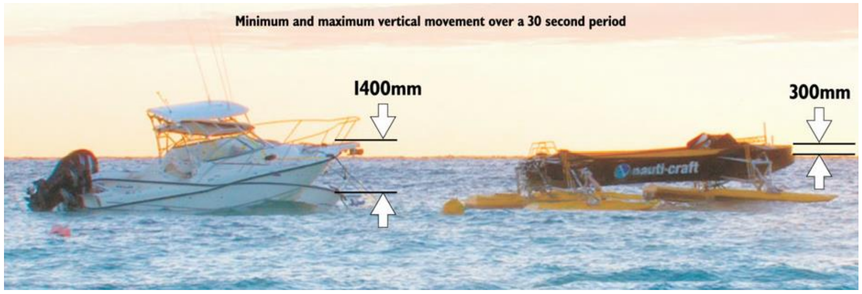


Figure 1-8 Vertical Movement of the Prototype and a Conventional Monohull [14].

2 Design and Build Scaled Flaps on V-Shape Scaled Boats

The scaled boat model shown in Fig (2-1) is a Revolt 30 high-speed vee-shape boat.

Hull length is 30", and 9.125" width, and the propulsion is provided by an AquaCraft 1800 KV 6 pole motor. The specifications for this model are given in appendix A.

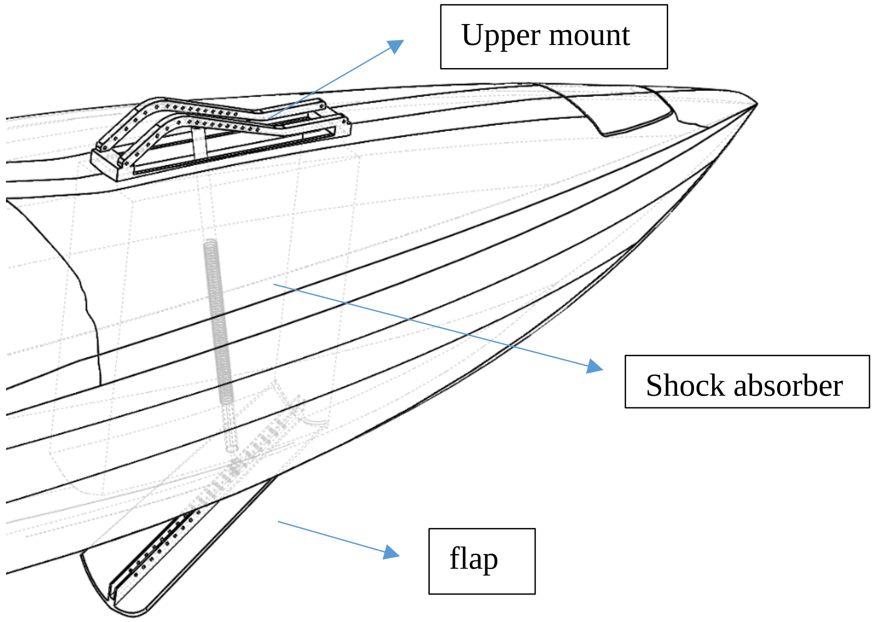
Figure 2-1 Scaled Vee-Shape Hull Boat [appendix A]

In this study, a suspended mechanism design is proposed to reduce the vertical acceleration on high speed boat. The mechanism consists of flap which is piece cut from the bottom of the boat and suspended via shock absorber components.

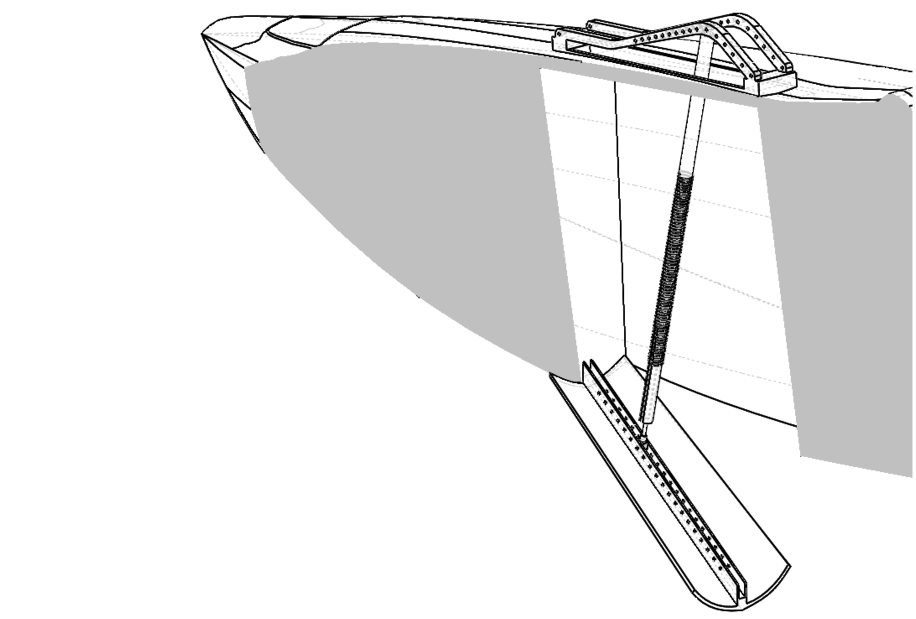
The small-scale boat with flaps was conceived, designed and manufactured by Prof. Grenestedt [12], who also performed all tests. Amer installed the data acquisition system.

All tests recorded in this Thesis were performed during a two-hour period in a single day. Amer evaluated the data.

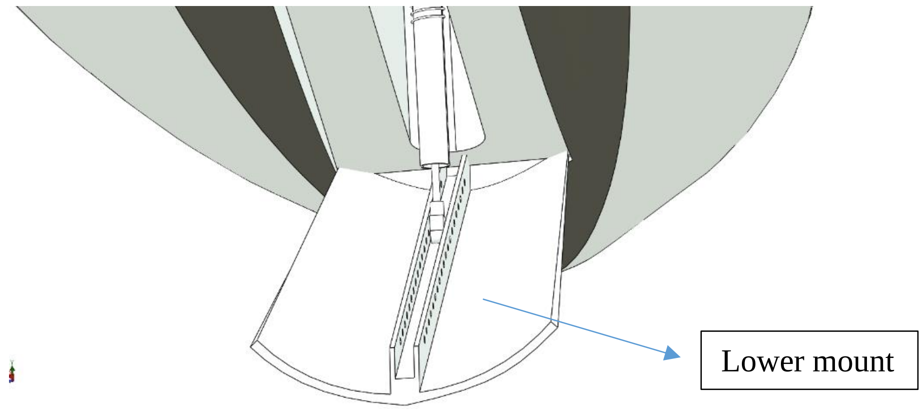
Fig (2-2) (a,b,c) represents the mechanism. The flap length to hull length ratio is 1/5 hinged to the boat bottom at distance equal to the same ratio from the front of the boat with different holes on upper and lower mounts that provide fixability to change shock absorber fixation points. Fig (2-3) shows the assembled mechanism on scaled boat.



(a)Flap Mechanism



(b) Cross Section Flap Mechanism



(c) Flap Lower Mount

Figure 2-2 Flap Mechanism

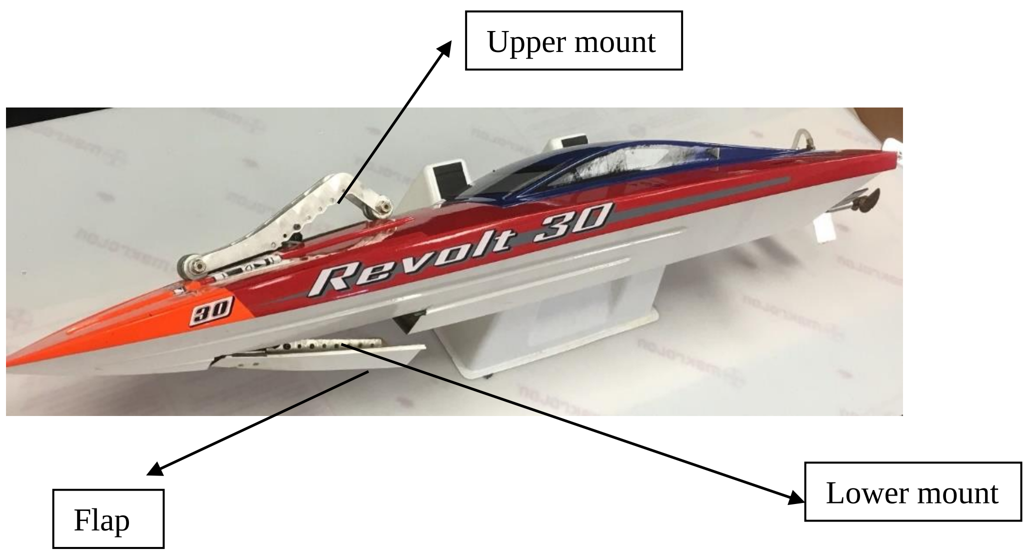
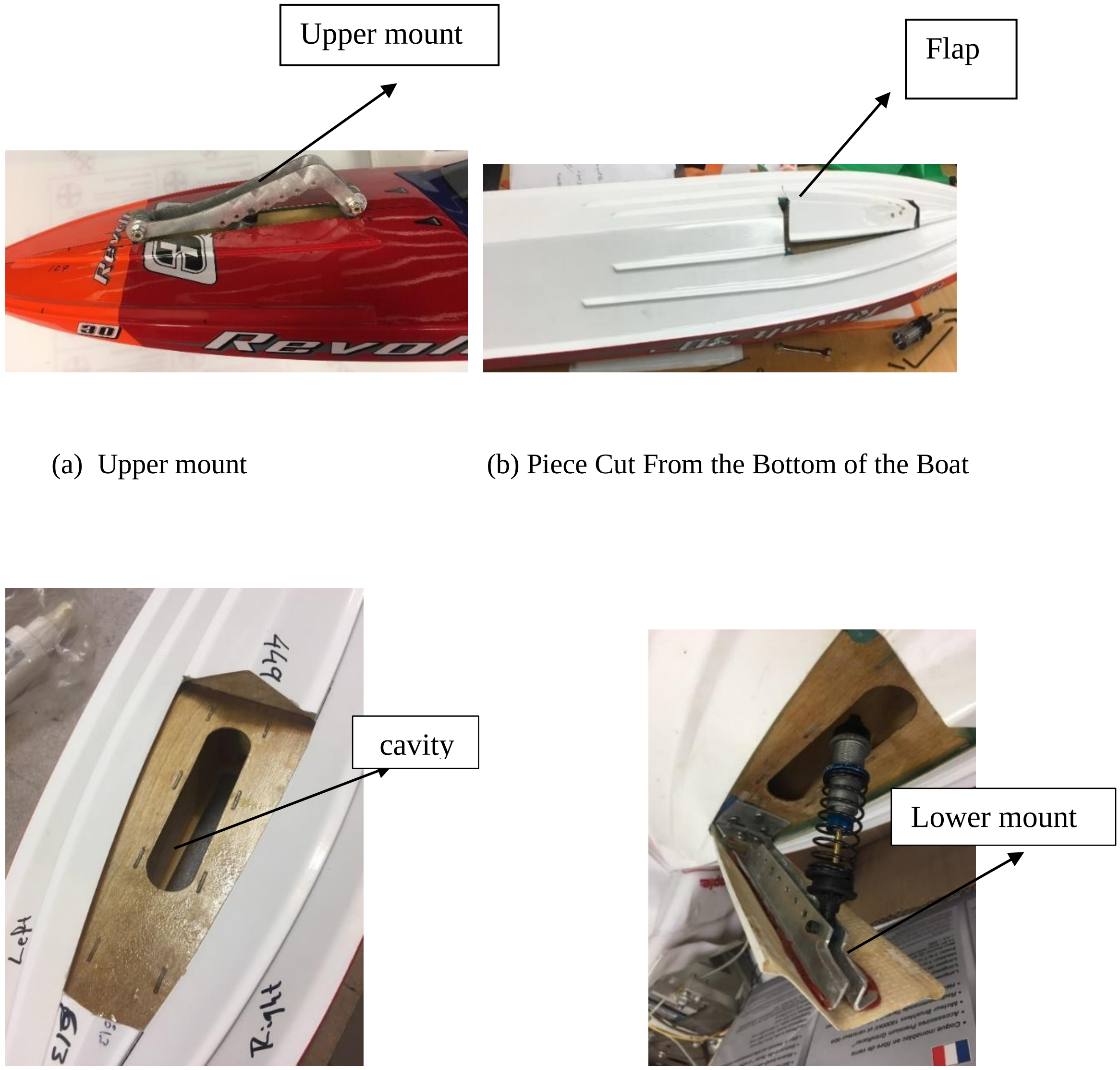


Figure 2-3 Boat with Flap Mechanism

Fig (2-4) shows detailed mechanism consists of the (a) upper and (b)lower mounts,

(c) flap and (d) spring cavity to allow install the damping components.



(a) Upper mount (b) Piece Cut From the Bottom of the Boat

(c) Shock Absorber Cavity (d) Lower Mount

Figure 2-4 Model Boat with Flap Mechanism

2.1 Shock Absorbers Types

The shock absorbers absorb, or dissipate, modern shock absorbers are velocity sensitive hydraulic damping devices – meaning the faster the suspension moves, the more resistance the shock absorber provides. They reduce the rate of 1) Bounce,2) Roll or sway, 3) Brake dive and Acceleration squat [15].

There are several shock absorbers designs in use today such as Twin Tube – Gas Charged Design, Twin Tube – PSD Design , Twin Tube -ASD Design, and Mono-Tube design which offers numerous advantages [16].

In this study the Mono-tube design scaled shock absorber is used, Fig (2-5) (a-b) show the scaled shock absorber with the assembled components with different piston orifice dimeters.

(a) Scaled Shock absorber   (b) Shock Components Different Piston Orifice Size

Figure 2-5 Scaled Shock Absorber used for Boat

The scaled shock absorber of outer diameter 16mm, stroke of 25.4 mm rod diameter 3mm, shock piston with two different orifices diameters 1.5 mm,1.7mm, three different fluid viscosities used in the study 60 cst , 40 cst, 20 cst. As shown in Fig (2-6).

Figure 2-6 Different Viscous Oils

2.2 Design and Building the Shock Absorber Dynamometer

Experimental characterization of the different types of shock absorbers, at different speeds, with different oil viscosities and piston orifice diameters before installed on the boat is important to measure the system efficiency.

For the scaled size of used shock absorber, it is very difficult to find readymade instrument to measure shock absorber characteristics, so design and build special shock absorber dynamometer was vital for the study.

The shock dyno was conceived, designed, manufactured and tested by Mr. Maroun. Amer developed the data acquisition system. Mr. Maroun and Amer performed tests. Amer evaluated the data.

2.2.1 CAD/CAM Model of Shock Absorber Dynamometer Mechanical Components

The dynamometer mechanical components were designed by Mr. Maroun and manufactured at Lehigh University Labs, Fig (2-7) show the assembled dynamometer cad model, which designed and built to be installed on lathe as a rotary motion input.

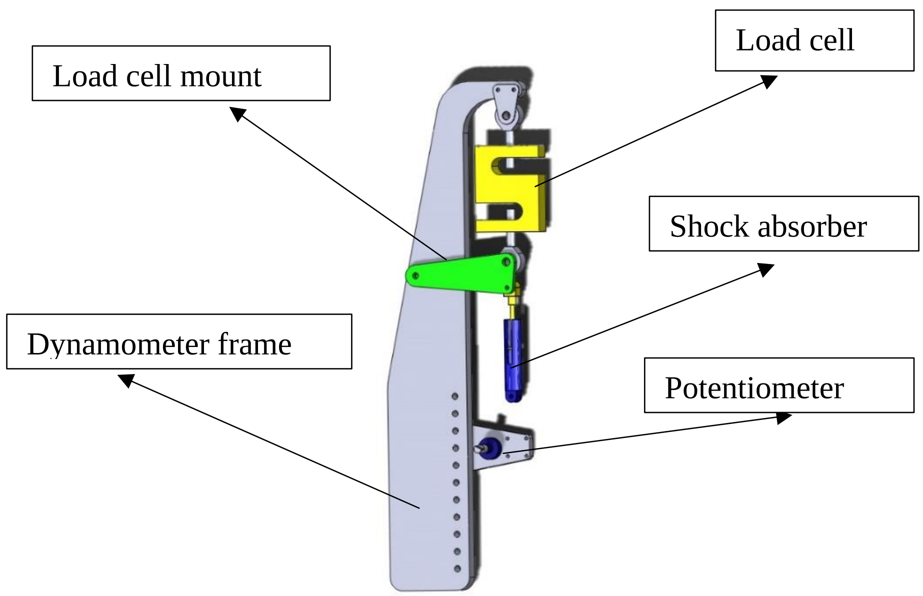


Figure 2-7 Assembled Cad Model of Dynamometer

The shock absorber dynamometer frame and parts were made of aluminum and installed on the lathe as shown in Fig (2-8).

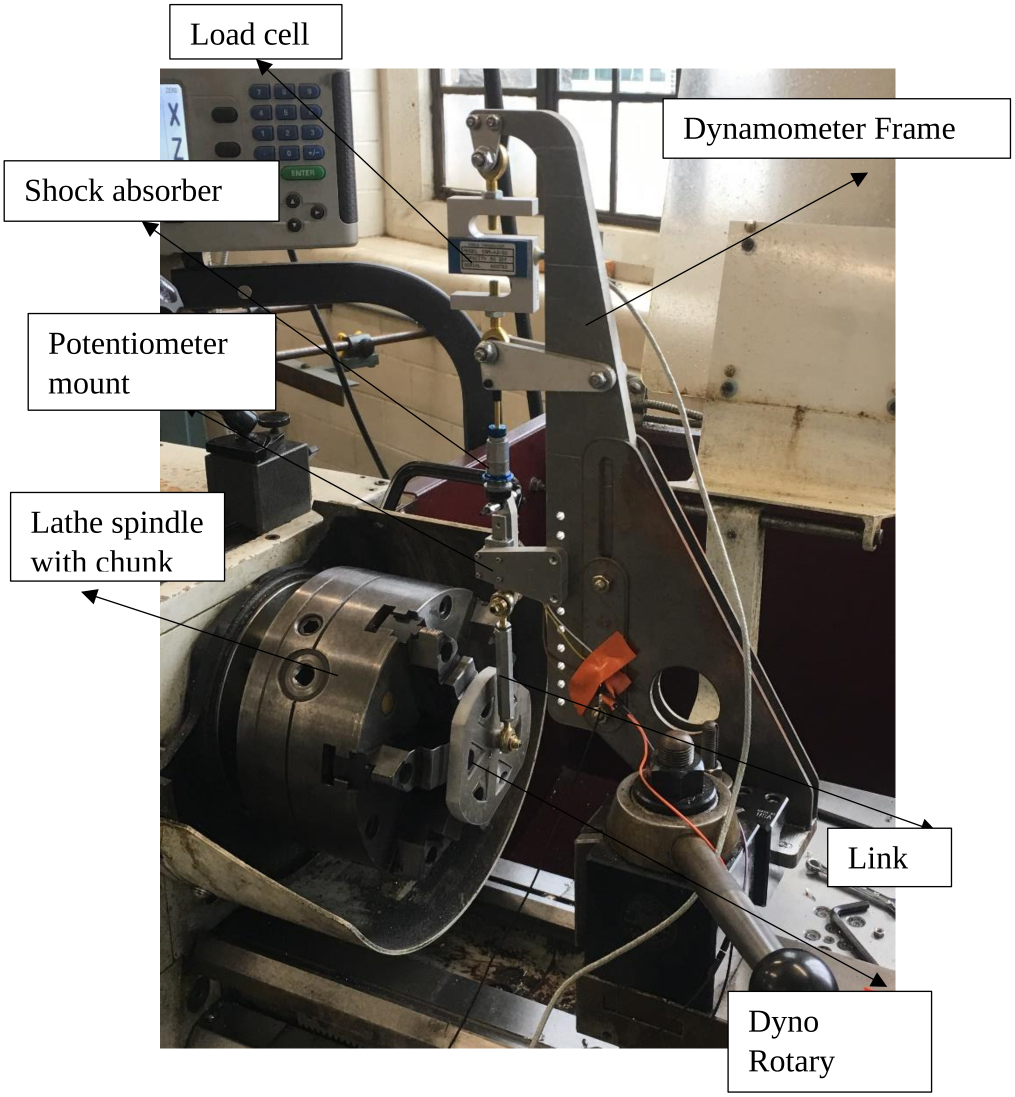


Figure 2-8 Dynamometer Installed on Lathe.

2.2.2 Shock Absorber Dynamometer Instrumentation

The dynamometer was equipped with S type Load cell that has a max load capacity of 50lb as shown in Fig (2-9). The accuracy– (max error) Nonlinearity–% FS r0.05, Appendix B show the load cell specifications.

Three-terminal mechanically operated rotary analogue device (potentiometer) used to measure the linear displacement of shock absorber

Figure 2-9 Load Cell

A data acquisition system provided signal conditioning and recording of all sensor data. National Instruments NI 9205 with 16 differential analog inputs, 16-bit resolution, and a maximum sampling rate of 250 kS/s. Each channel has programmable input ranges of ±200 mV, ±1 V, ±5 V, and ±10 V.

the specifications are shown in appendix C.

An amplifier circuit was used to amplify the load cell output signal to adopt with data acquisition instrument specifications is in appendix D.

LabView interface code was developed for monitoring sensors signals and calibration of the load cell**.**

2.3 Shock Absorber Dynamometer Data Analysis

To generate shock absorber characteristics velocity-force curve using the raw data, MatLab code was developed based on following steps

1) Filtering the output data using a smoothing algorithm, 2) Fitting the curve according to the kinematic equation for dynamometer rectilinear motion [15], 3) Solve for nonlinear force, then generate the velocity-force curve at different speeds 120rpm ,470rpm,800rpm.

Fig (2-10) Data of potentiometer displacement signal for scaled shock absorber.

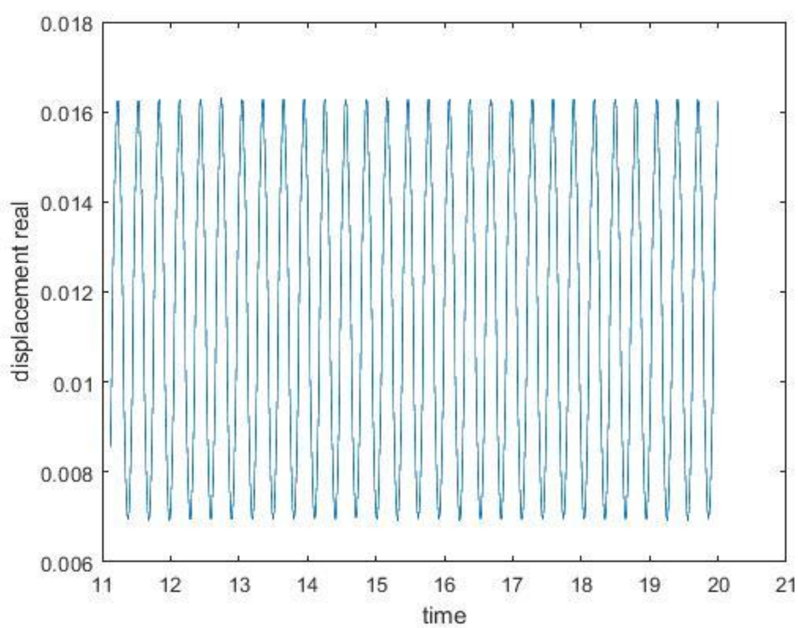


Figure 2-10 Displacement Signal

Fig (2-11) show the signal irregular peaks form that affects the accuracy of calculating the time period.

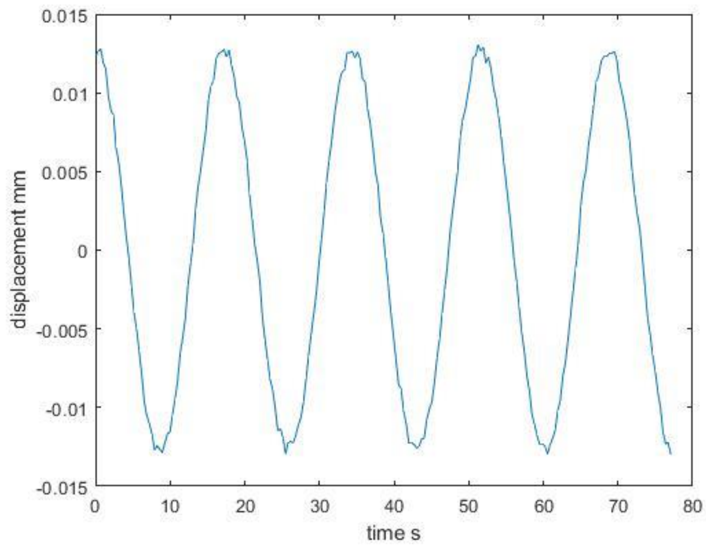


Figure 2-11 Displacement Signal

Schematic drawing with a free-body diagram that shows the shock absorber and the direction of the force and displacement is shown in Fig (2-12)

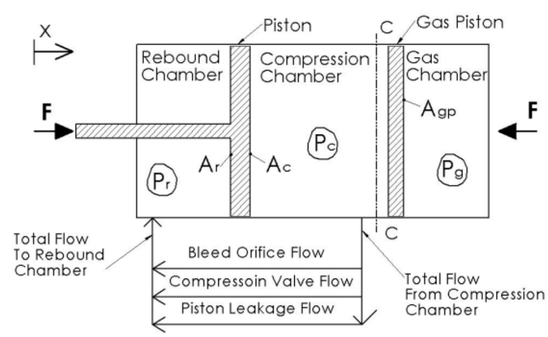


Figure 2-12 Schematic Drawing with Diagram of Shock Absorber

Fig (2-13) show the signal peaks locations

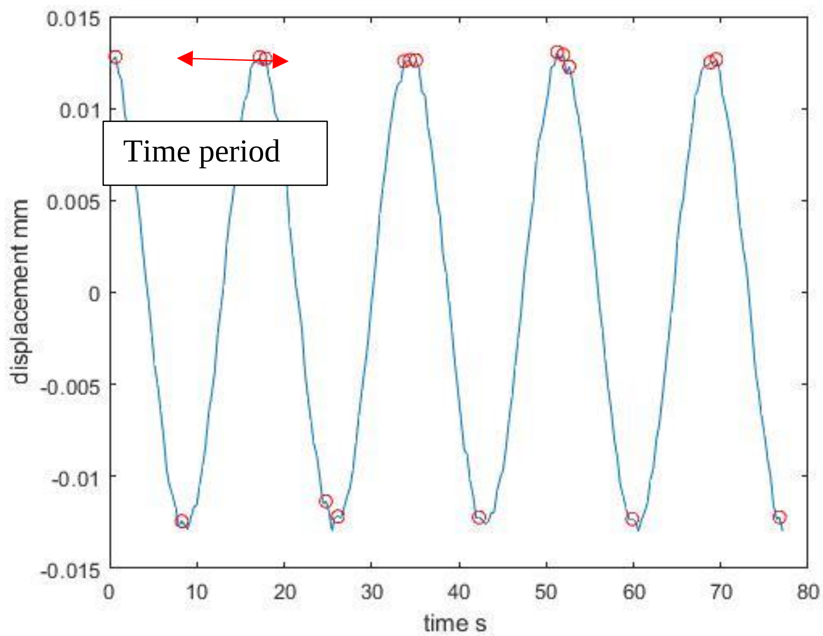
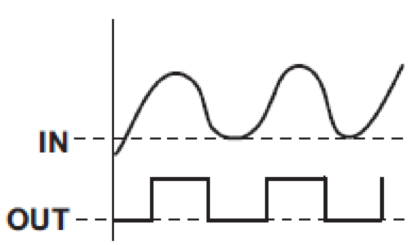


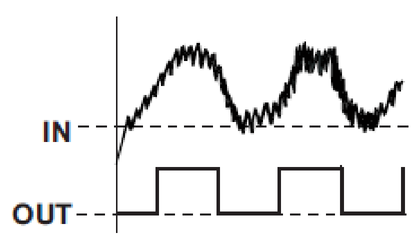
Figure 2-13 Peaks Locations

Schmitt triggers are commonly used in signal conditioning applications to

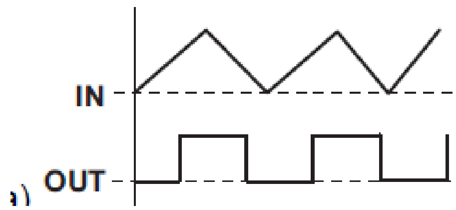
to 1) Change a sine wave into a square wave, 2) Have noisy signals that need to be cleaned up,3) Have slow edges that need to be converted to fast edges as shown in Fig(2-14)(a-b-c) remove noise [17][18][19] .



(a) Square Wave



(b) Noisy Signals



(b) Fast Edges

Figure 2-14 Schmitt Trigger

Schmitt Trigger method is applied on the acquired displacement signal to achieve an accurate estimation of time and phase shift to obtain an accurate fitted curve as shown in Fig (2-15)

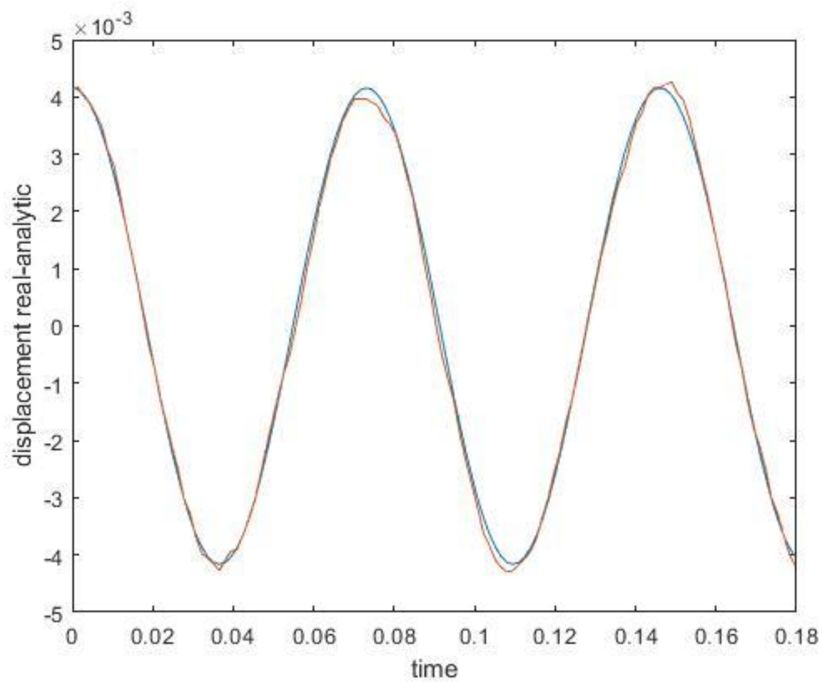


Figure 2-15 Fitted Signal

Force sign, positive for compression, negative for rebound, Fig (2-17) shows force

Vs displacement curve.

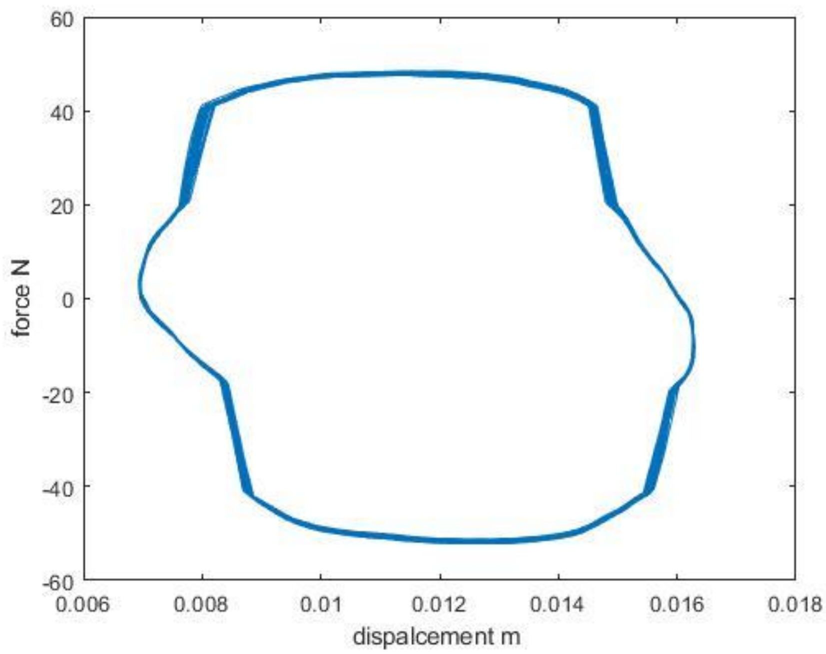


Figure 2-16 Force vs displacement curve

Fig (2-18) shows force Vs time curve

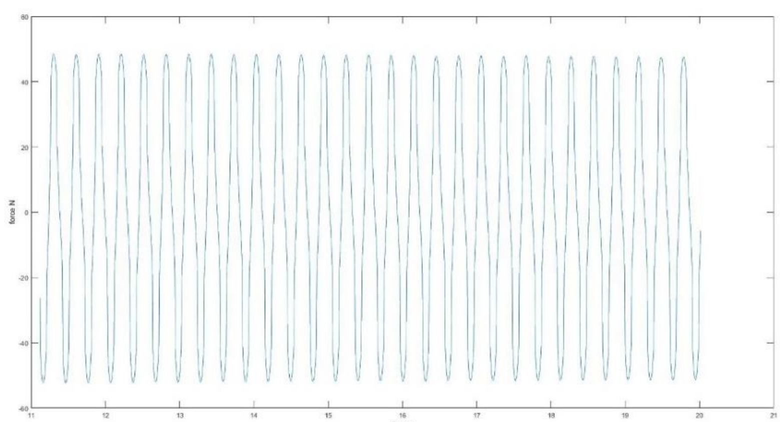


Figure 2-17 Force vs Time

Solve for Nonlinear Force and Generate the (F-V) Curve at Different Speeds

In order to generate a characteristic curve for the shock absorber, the damping force needs to be determined, while the measured force acquired from load cell representing a total force. The measured force includes preload force, spring stiffness force considering the air in the bladder as a spring effect [20][21], and damping force.

To separate these forces, we first determine the preload force at velocity = 0.

Then by finding the mean values of max and min force at the zero value of velocity after subtracting the preload force we can determine the spring force. Then subtracting these values from the total force, we can determine the damping force and generate the velocity vs force curve for the shock absorbers that can be done at different speeds.

Fig (2-19) shows the velocity-force curve for shock absorber at 800 rpm that speed chosen as max speed that the shock absorber could be suspected to during operation when running the boat MatLab code that generate the dynamometer curves is located in appendix E.

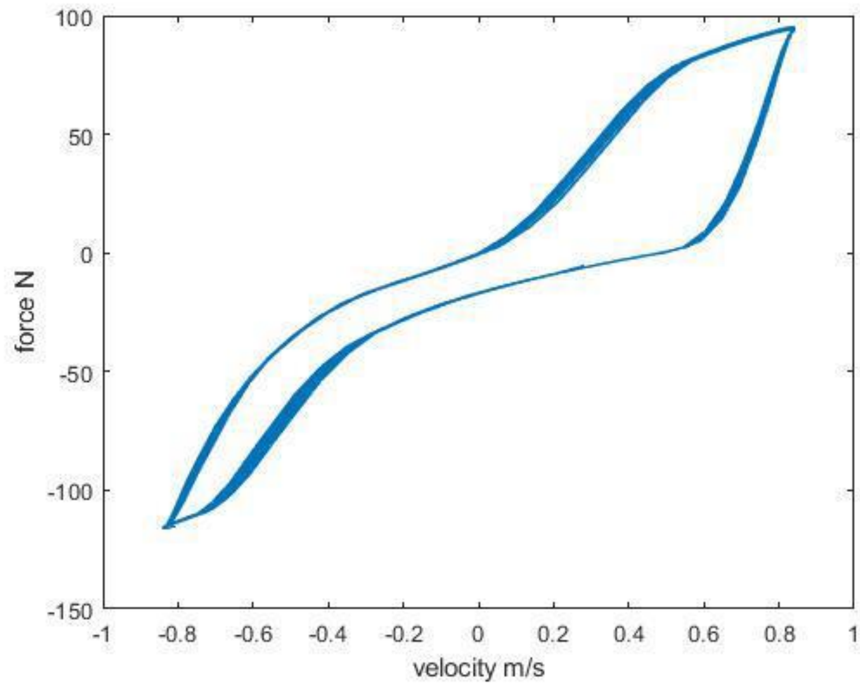
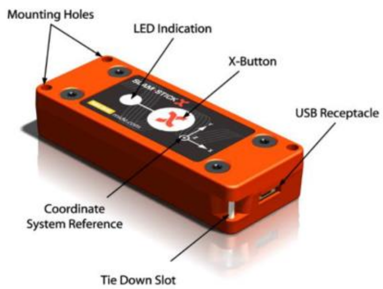


Figure 2-18 Shock Absorber F-V Curve

3 Boat Instrumentation and Data Acquisition

In an effort to study the effect that the flap mechanism had on reducing the slamming forces, tests were conducted under a variety of sea states. The tests used a scaled model boat with a range of different parameters for the shock absorbers. Measurements were acquired using a data acquisition system, which took data from an accelerometer and a GPS unit.

Slam Stick_ X DC-response accelerometer [22][23], which can measure down to zero hertz was used to measure the gravity vector and other sustained accelerations as shown in Fig (3-1).



Specification	Slam stick x
MEMS Accelerometer	±16g1 3,200 Hz | 13 bit
Piezoelectric Accelerometer	500g 20,000 Hz | 16 bit
Piezoresistive Accelerometer	--------

Figure 3-1 Slam Stick Sensor

The Slam Stick X incorporates a MEMS 3-axis piezoelectric accelerometer, temperature sensor, pressure sensor, specifications located in appendix F.

GPS was also used to determine the boat speed using a data acquisition rate of 10Hz, Speed Accuracy approx.+- 0.1 m/s, Current draw less than 40 mA when tracking , Dimensions approx. 1.4” x 0.9” x 0.3” (35x20x8mm), Position accuracy approx. 8.2 ft (2.5m). The GPS sensor was connected to Eagle Tree data logger device which save the GPS data into permanent memory, which retains the data even when the power is removed. Specification is in appendix G.

4 Boat Testing and Data analysis

A few photographs taken during the construction of the scaled boat used in this study, is shown in Fig (4-1). These pictures also identify the location of some of the critical sensors.

Pre- testing check is shown in appendix H:

Figure 4-1 Overall Boat Installation

4.1 **Boat Testing**

Experiments were conducted in the Lehigh River, USA on June. 25, 2019, under sea state 1 conditions[24]. the river water speed was measured by allowing the boat to float in the water and determining the distance traveled within a specific time from the GPS unit. That is how the sea state was determined. Fig (4-2) shows the GPS speed of water before running the tests. The average speed was less than 10 km/h. The tests consisted of many short, constant track, constant speed segments.

Five experiments were performed with the different shock absorbers parameter (orifice diameter), spring rates, oil viscosity, the time duration for each test 5-8 min, the average speed was 45 km/h measured by using data obtained from the GPS.

The boat's total weight was 2689.9 g, the center of gravity, CG, was determined to be 20 inches from the front.

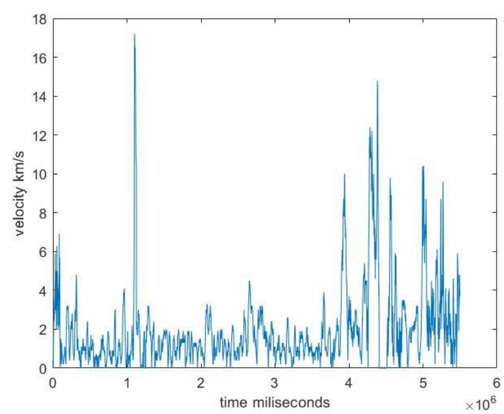
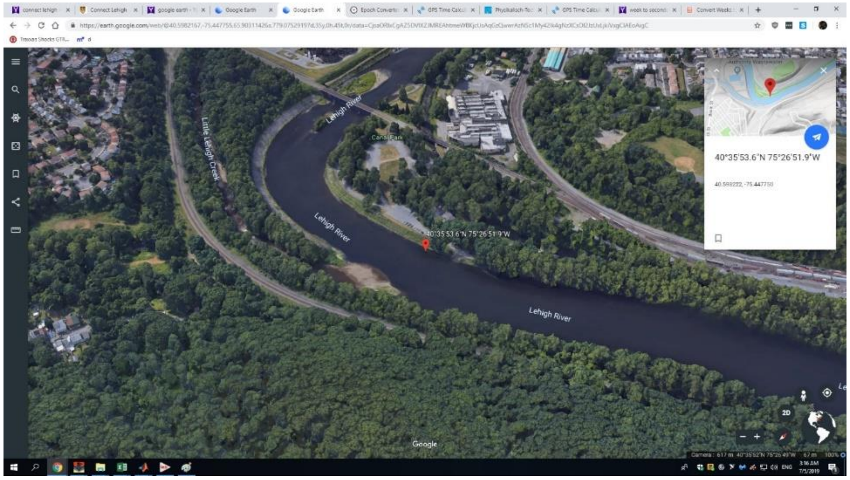
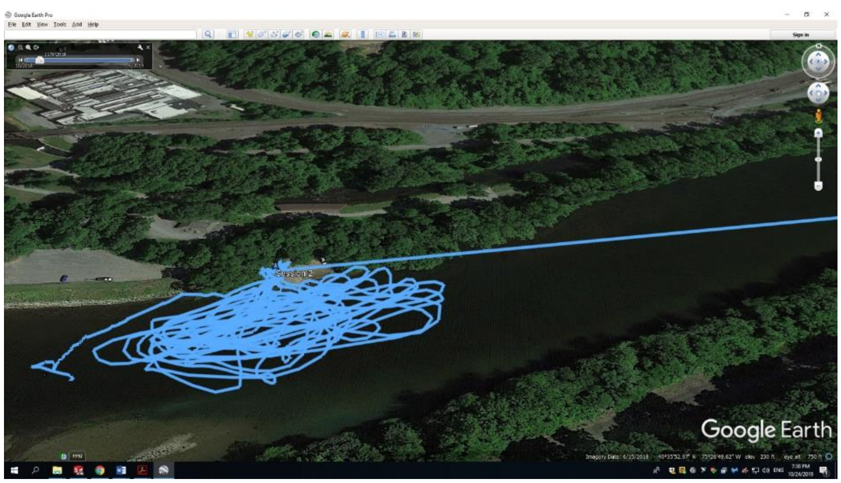


Figure 4-2 Water Speed

Fig (4-3) (a-b) show the tests GPS location and boat path



(a)Test Location



(b)Test path

Figure 4-3 GPS Location Boat Testing

Fig (4-4) -(4-5) show first test GPS path and boat running speed.

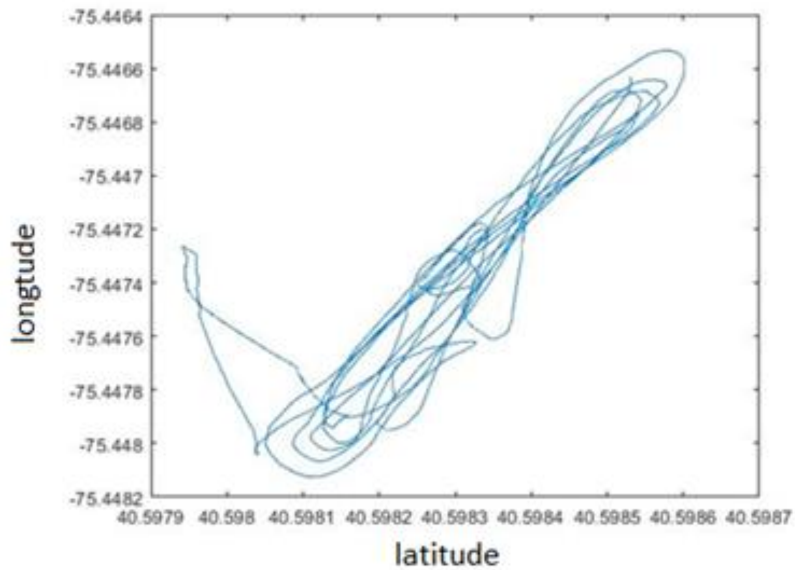


Figure 4-4 GPS Path for First Test

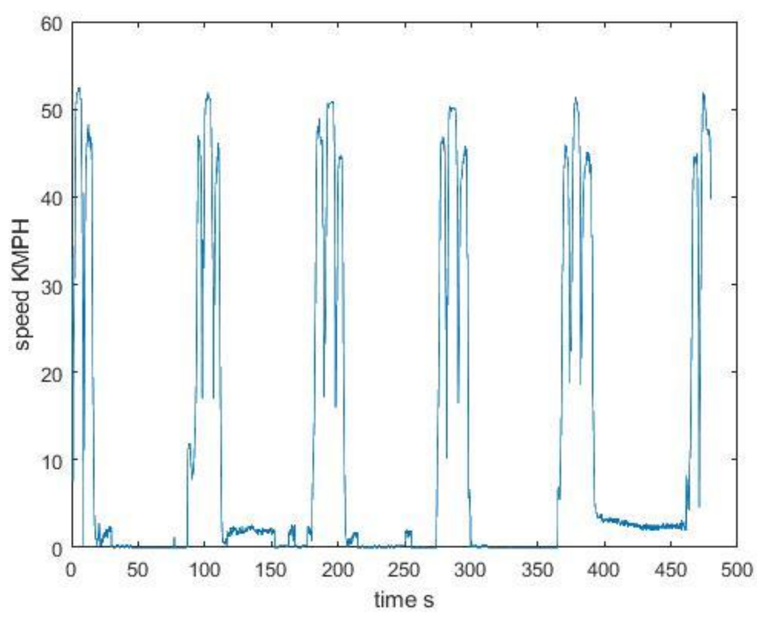


Figure 4-5 GPS Obtained Speeds for First Test

Table 1 represents the boat tests

Test Number	Shock absorber oil viscosity	Shock absorber piston orifice diameter	Spring rate	Shock absorber fixation points
Test #1	high viscosity oil 60vs	orifice diameter 1.5 mm	preloaded to max shock spacer distance 1.582 N/mm	fixed in 3-3 holes up and down from the front of the boat holes
Test #2	high viscosity oil 60vs	orifice diameter 1.5 mm	without preloaded 1.582 N/mm	fixed on 3-3 holes from up and down from the front of the boat
Test #3	low viscosity oil 40vs	orifice diameter 1.7 mm	without preloaded 1.582 N/mm	fixed on 3-3 holes from up and down from the front of the boat
Test #4	Fixed flap bottom without using shock absorber at all.			

Test #5	low viscosity oil 40vs	orifice diameter 1.7 mm	without preloaded 4.794 mm	

Statistical Analyses

One aspect of data analysis methodology that has been adopted for high-speed planning craft

involves the assessment of peak vertical acceleration values encountered during individual wave slam events, Peak acceleration amplitudes recorded during a test sequence are tabulated, and averages are calculated using a peak-to-trough methodology adopted from ocean wave measurement techniques[29][30][31][32]. A peak detection algorithm was used to identify slamming events and assess parameters[33] [34].

The peak detection method was calculated by extracting peak accelerations from highest to lowest, selecting the highest the 1/Nth peak accelerations which computed using equation (1).

$$A_{1/M} = \frac{1}{N/M} \sum_{i=1}^{N/M} A_i$$

$A(t)$ is the acceleration time history, A_i are the individual acceleration peaks (extracted from an acceleration time history), sorted in such a way that the largest amplitude peak acceleration has i =1 and the lowest peak acceleration is i =N. The ratio N/M is a rounded whole number. N is the number of A_i peak accelerations greater than the threshold value and M is 3, 10, or 100.

The peak threshold for the algorithm was chosen as the mean value of the signal plus the standard deviation. A minimum peak separation selected to be 0.05 seconds.

Since the distance between waves was on the order of 0.5 m and the speed of the boat on the order of 10 m/s. The time interval between slams would be expected to be on the order of 0.5/10=0.05 s.

The detected peak data was further reduced by identifying the average of the largest 1/3 magnitude slamming events[33][35][36].

Simple calculations were done to verify the acquired acceleration component perpendicular to the boat surface during rotation, Fig (4-6) show schematic drawing of boat during rotation.

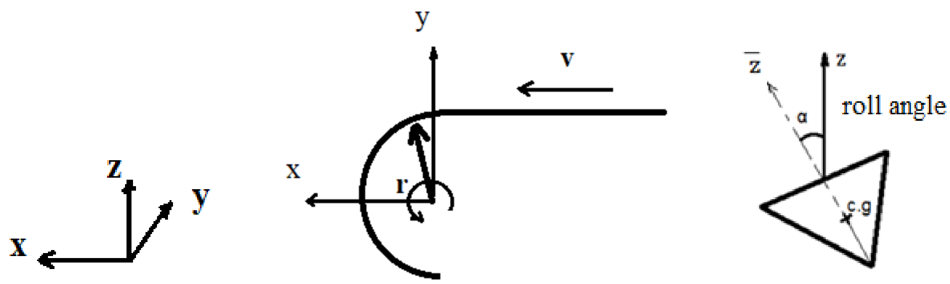


Figure 4-6 Schematic Drawing of Boat During Rotation

Using the GPS data correlated to the quatrain data that show the yaw angle change of the boat which identify the boat rotation. The boat speed at time t=3 s, 30km/h as shown in Fig (4-7) GPS data during boat turning.

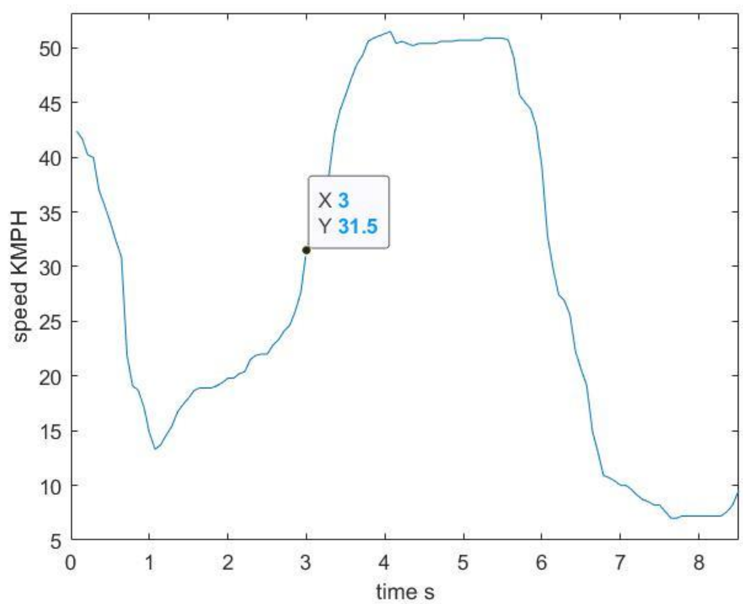


Figure 4-7 The Boat Rotation Speed at Time t= 3s

Fig (4-8) show the roll angle at the same time = 11.92 degree from the boat yaw angles acquired accelerometer sensor.

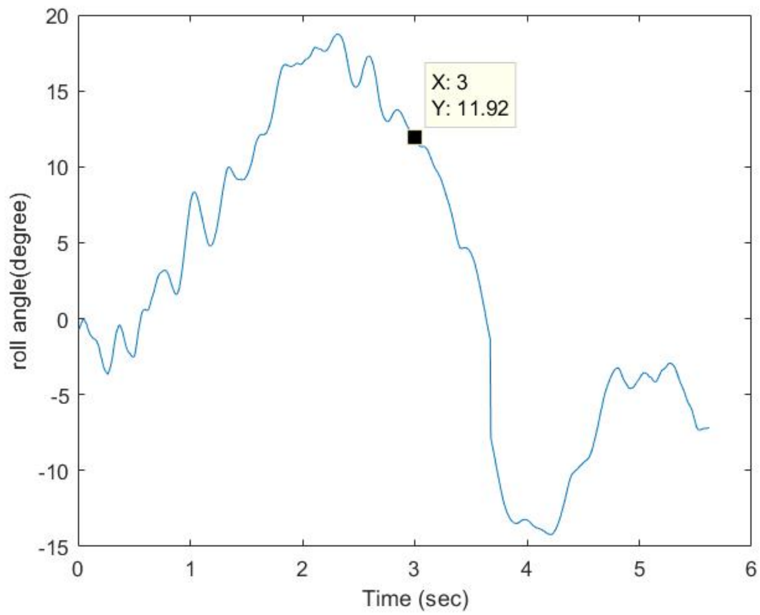
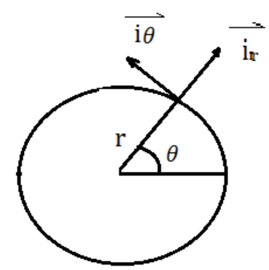


Figure 4-8 Boat Roll Angle During Turn

Boat rotation radius assumed to be 2m using the test video



Assume constant velocity v= 8.75 m/s

Boat roll angle = 11.92 at t=3s

Linear velocity $v = r\dot{\theta}$

$$\vec{r} = r\overrightarrow{\iota_r}$$

$$\vec{v} = \frac{d\vec{r}}{dt} = \dot{r}\,\overrightarrow{\iota_r} + r\dot{\theta}\,\overrightarrow{\iota_\theta}$$

$$\vec{a} = \frac{d\vec{v}}{dt} = (\ddot{r} - r\dot{\theta^2})\overrightarrow{\iota_r} + (r\ddot{\theta} + 2\dot{r}\dot{\theta})\overrightarrow{\iota_\theta}$$

Assume constant radius $\dot{r} = 0, \ddot{r} = 0$, then the tangential acceleration=0

$a_{\bar{z}} = -r\ddot{\theta}^2 \sin(\alpha) = 7.8$ m/s^2

The acceleration component acquired from at t = 3 s, $a_{\bar{z}}$ =6.9 m/s^2 as shown in Fig (4-9).

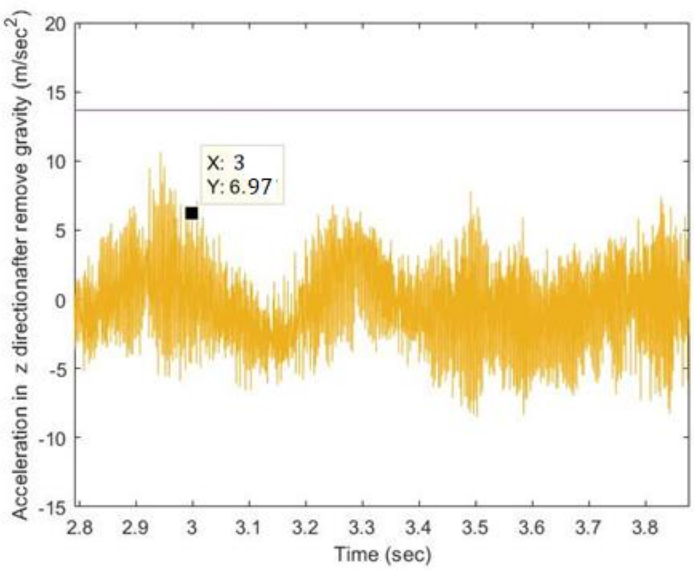


Figure 4-9 Acceleration Component Perpendicular to Boat Surface

The results verify the acquired vertical acceleration component perpendicular to the boat surface during rotation

In order to get accurate analysis will apply the peak detection algorithm on vertical acceleration signal acquired during the straight high-speed legs of the trajectory without the data during turns since the roll angle play a factor during rotation and the acquired signal does not show the vertical acceleration on the boat.

In order to separate the acquired vertical acceleration during boat turning accurately will use the acquired yaw angles from the accelerometer and pick the time interval while the boat moving straight forward as shown in Fig (4-10), the periods surrounded by a circle represents the boat moving straight forward, then determine vertical acceleration for the same time.

The average results of 6 straight shots for each test was calculated.

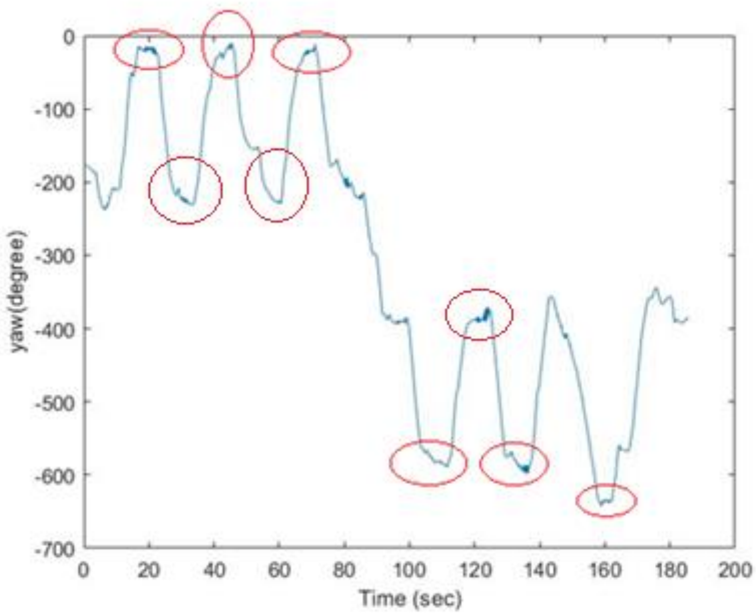


Figure 4-10 Yaw Angles of the Boat

Fig (4-11) show the accelerations in the z-direction (perpendicular to boat surface) and threshold as a red line, boat average speed 45KM/H for the 3min of first test including both translation and rotation motion.

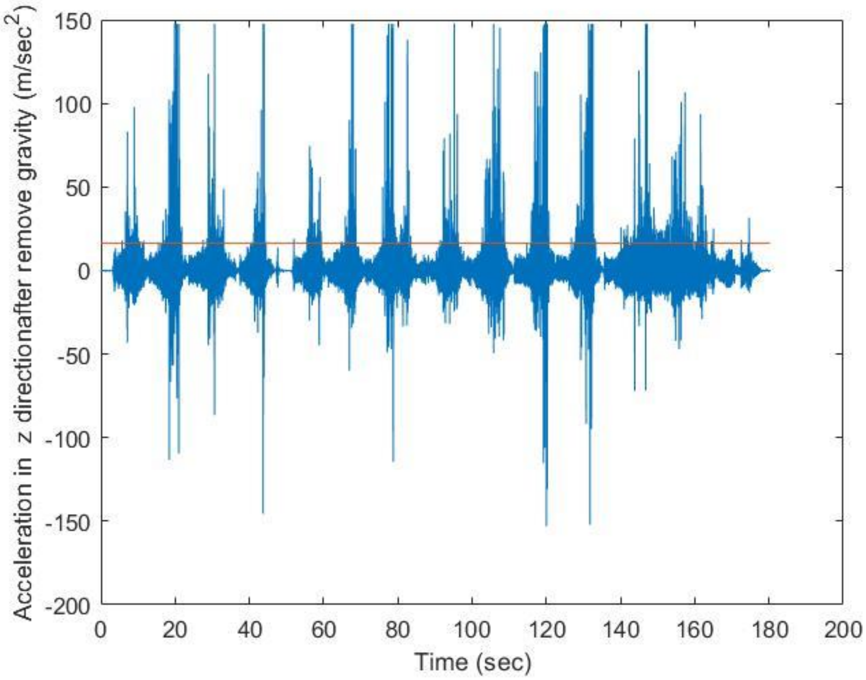


Figure 4-11 Vertical Acceleration 3min of the First Test

Fig (4-12) shows vertical acceleration of the boat moving in straight forward

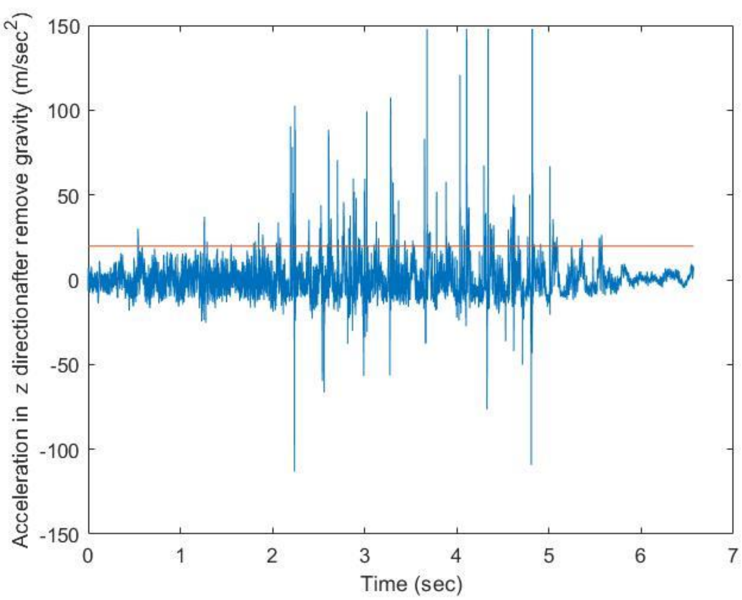


Figure 4-12 Vertical Accelerations While Move Straight

Fig (4-13) show the peak detection applied on vertical acceleration while the boat moving forward

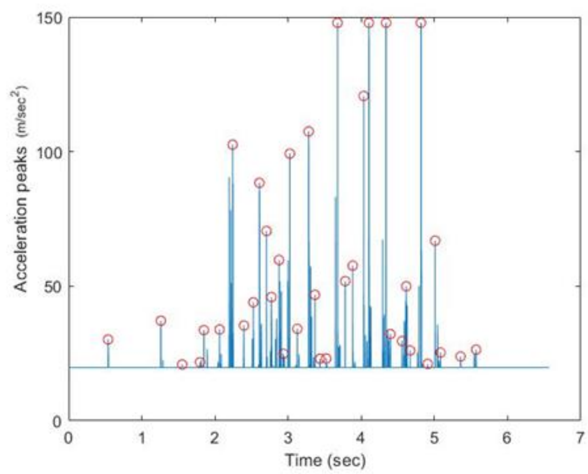


Figure 4-13 Acceleration peaks during moving straight

A histogram format that illustrates the statistical distribution of the peak accelerations computed is shown in Fig (4-14).

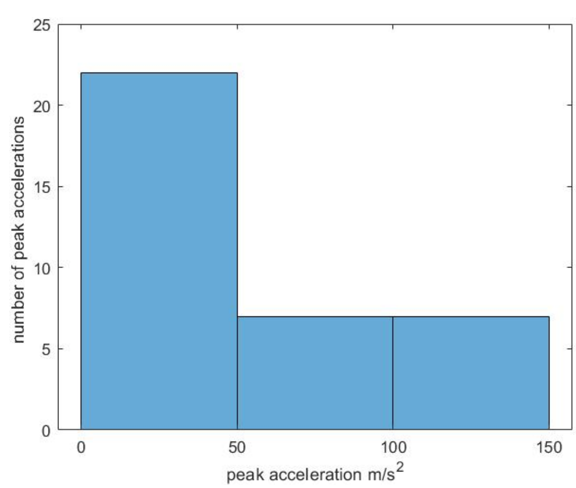


Figure 4-14 Histogram of Acceleration Peaks

Average of the highest 1/3 peaks for first round = 103.85 m/s^2

The same procedures were applied on other 6 straight movement of the boat for the same test.

A histogram format that illustrates the statistical distribution of the peak accelerations computed is shown in Fig (4-15).

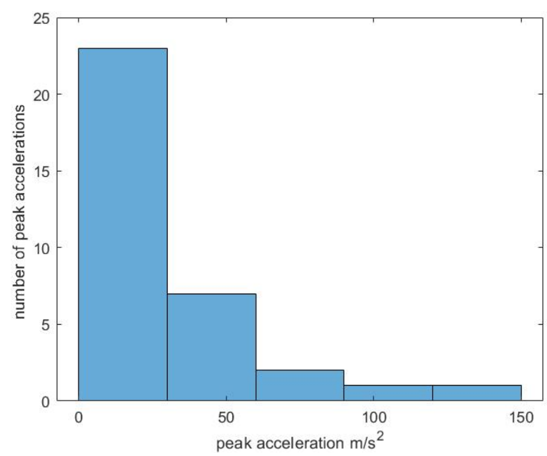


Figure 4-15 Histogram of Acceleration Peaks

Average of the highest 1/3 peaks for 2nd round = 56 m/s^2

A histogram format that illustrates the statistical distribution of the peak accelerations computed is shown in Fig (4-16).

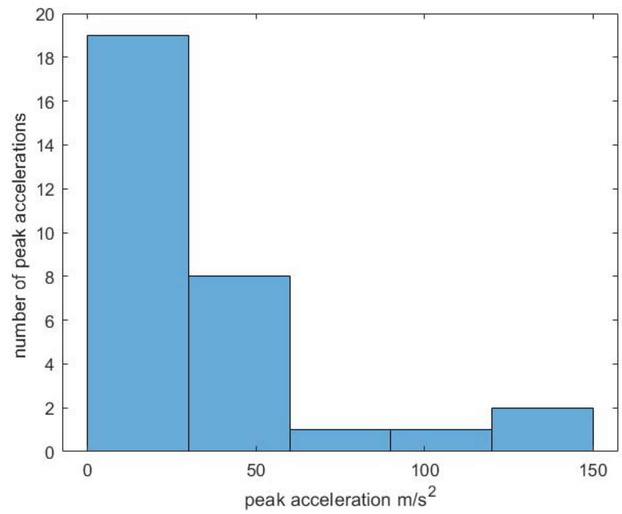


Figure 4-16 Histogram of Acceleration Peaks

Average of the highest 1/3 peaks for 3rd round is 55.941m/s^2

A histogram format that illustrates the statistical distribution of the peak accelerations computed is shown in Fig (4-17).

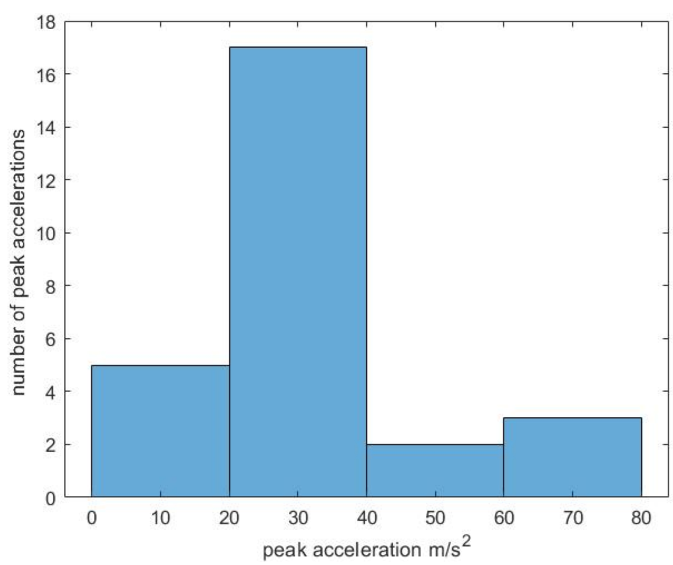


Figure 4-17 Histogram of Acceleration Peaks

Average of the highest 1/3 peaks for 4th round is 45 m/s²

A histogram format that illustrates the statistical distribution of the peak accelerations computed is shown in Fig (4-18).

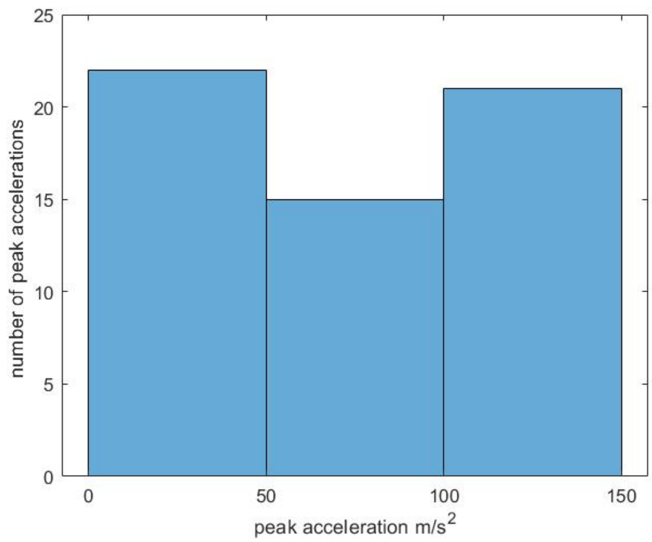


Figure 4-18 Histogram of Acceleration Peaks

Average of the highest 1/3 peaks for 5th round is 77.2 m/s^2

A histogram format that illustrates the statistical distribution of the peak accelerations computed of 6th round as shown in Fig (4-19).

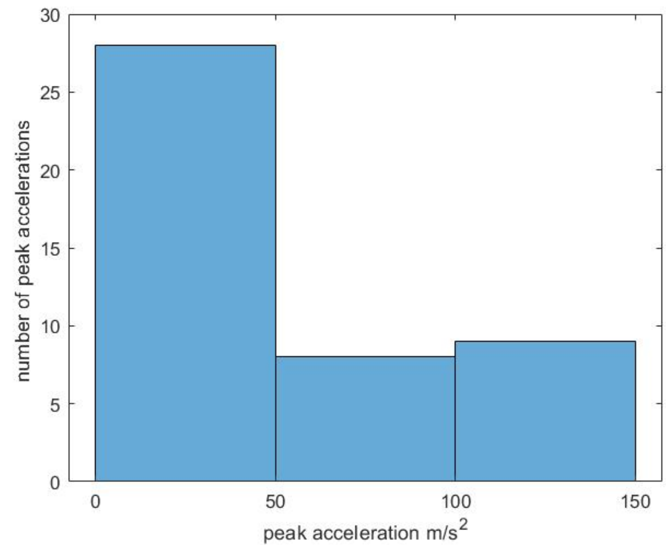


Figure 4-19 Histogram of Acceleration Peaks

Average of the highest 1/3 peaks for 6th round is 113 m/s^2

The total average of highest 1/3 peaks for first test = 77 m/s^2

Comparison average highest 1/3 peaks for five testes knowing that

these are preliminary results form a very limited number of tests is shown in Table2.

Table 2 Comparison average highest 1/3 peaks for five testes

Test	**Average of the highest 1/3 peaks**
Test #1	74.8 m /s^2
Test2#2	79.287 m/s^2
Test3#3	104.99 m/s^2
Test4#4	78.838 m /s^2
Test5#5	105.86m /s^2

The comparison shows that the 1st test shows a lower acceleration value. More testes need to be done where the flap is inclined by 16 degrees according to fixation points at 3 hole up and down as shown in Fig (4-20), (4-21).

Figure 4-20 Upper and Lower Fixation Points.

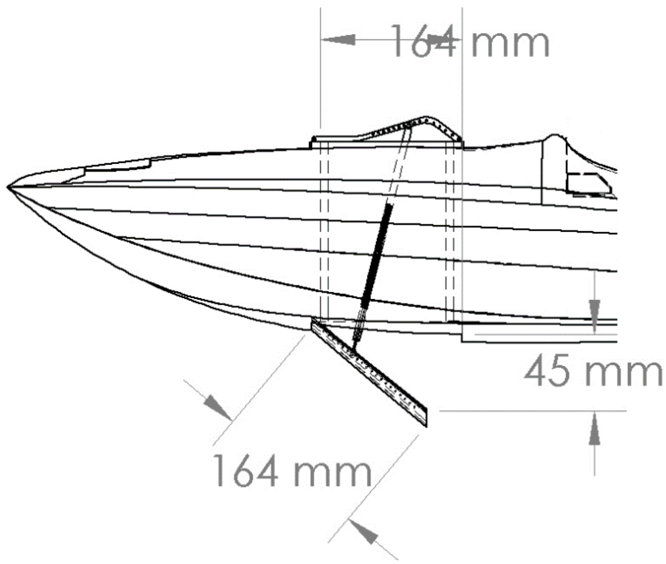


Figure 4-21 Flap Position for Third Test

5 Numerical Analysis of a Suspension Boat with four Passive Sponsons

A boat suspension system concept was developed to reduce vertical accelerations.

The suspension boats are patented by Prof. Grenestedt [12]. The boat in Fig (5-1) was designed by Prof. Grenestedt [12].

Scaled model of suspension boat also tested by running two boats with and without the suspension system, which show reduction of vertical displacement consequently reduction in vertical acceleration.

The tests and recorded video of the two boats running side-by-side were performed by Prof. Grenestedt [12] and Mr. Maroun.

It consists of a center-hull that is generally not in contact with the water and four sponsons connected to suspension links. In this study, mathematical models and numerical simulations were performed using a 10-degree of freedom model. The model represents the dynamic behavior of the suspension boat shown in Fig (5-1) using Kane's equation method, Fig (5-2)-(5-3) show the top and side view of suspension boat [37].

Different methods for obtaining equations of motion can be used, e.g., Lagrange's Equations dynamics, Newton-Euler. However, the ease of use of the various methods differs; some are more suited for multibody dynamics than others[38]. The Newton-

Euler method requires that force and moment balances be applied for each body taking into consideration every interactive and constraint force. Therefore, the method is inefficient when only a few of the system's forces need to be solved for.

Lagrange's Equations provides a method for disregarding all interactive and constraint forces that do not perform work. The major disadvantage of this method is the need to differentiate scalar energy functions (kinetic and potential energy). This is not much of a problem for small multibody systems but becomes difficult for large multibody systems [39].

Kane's method introduces a concept of generalized speed, partial velocity, partial angular velocity, generalized active forces and generalized inertial forces. To generate kinematic equations, expressions for the angular velocity and the angular acceleration of the rigid body should be derived [40].

Kane's method offers advantages of both the Newton-Euler and Lagrange methods without the disadvantages. With the use of generalized forces, the need for examining interactive and constraint forces between bodies is eliminated. Since Kane's method does not employ the use of energy functions, differentiating is not a problem. The differentiation required to compute velocities and accelerations can be obtained using algorithms based on vector products. Kane's method provides an elegant means to develop the dynamics equations for multibody systems that lends itself to automated numerical computation [41] .

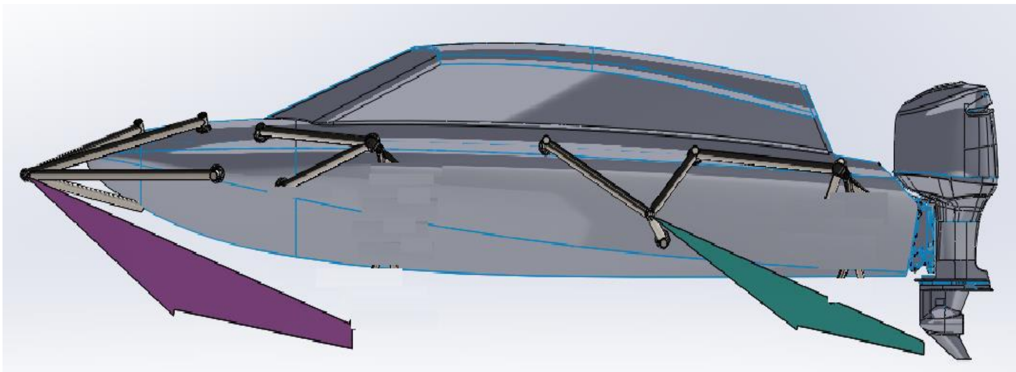


Figure 5-1 Boat with Sponsons

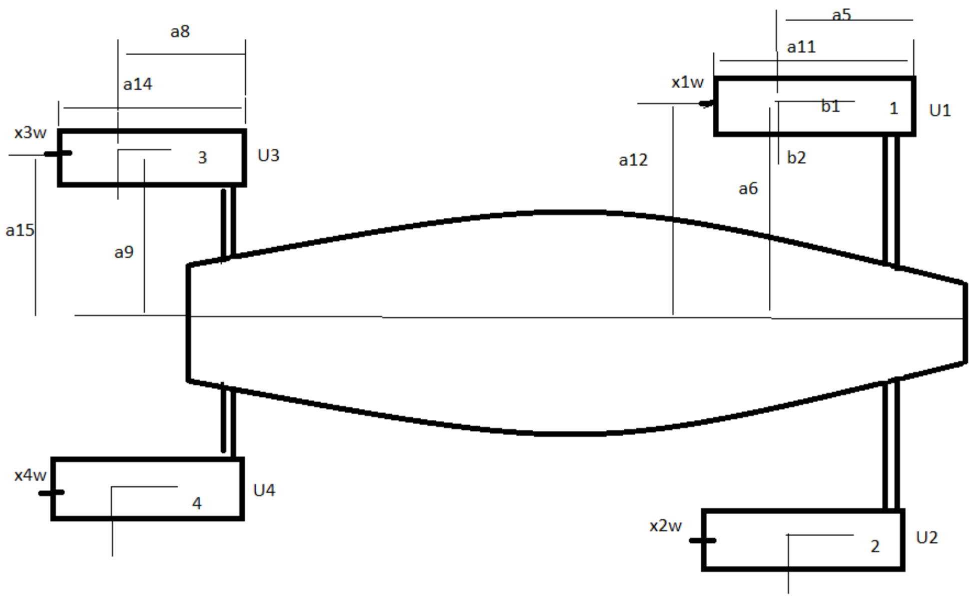


Figure 5-2 Boat with Sponsons Top View

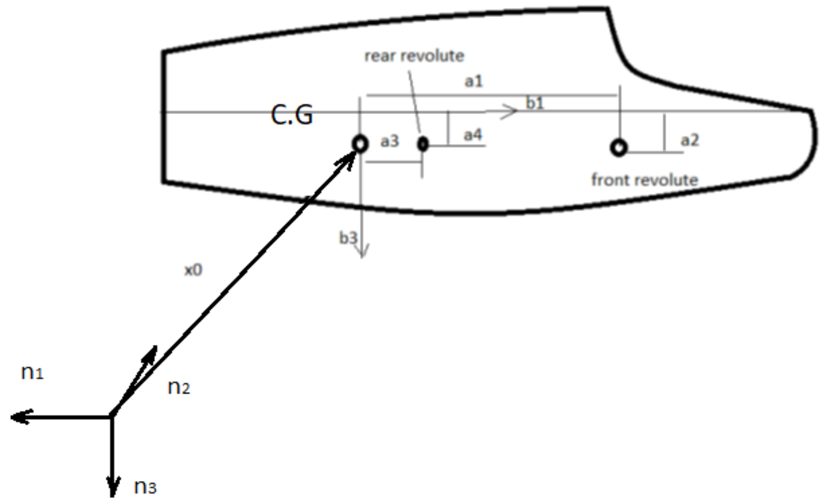


Figure 5-3 Boat with Sponsons Side View

In the following a global Cartesian coordinate system with coordinates x, y, z and orthonormal base vectors n_1, n_2, n_3 is used. The base vectors point West (n_1), North (n_2), and down (n_3), respectively. The dynamics of the suspension boat are described using the generalized coordinates Fig (5- 4) shows the Euler angles.

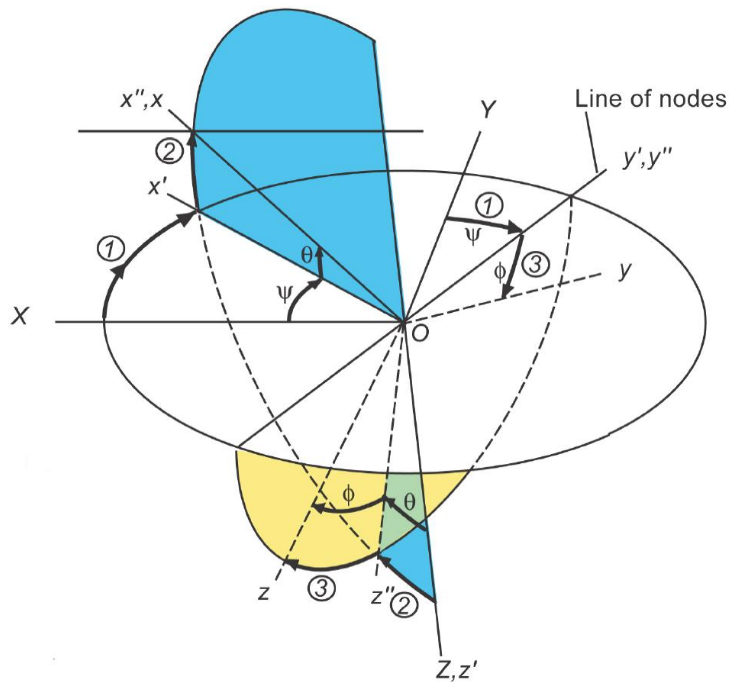


Figure 5-4 Euler Angles

Rotate by Ψ about z $\grave{x},\ \grave{y}\ ,\grave{z}$

Rotate by θ about $\grave{y}$ $\grave{\grave{x}},\ \grave{\grave{y}}\ ,\grave{\grave{z}}$

Rotate by ϕ about $\grave{\grave{x}},$ x, y, z

$$
\begin{aligned}
u_1 &= \dot{x} \\
u_2 &= \dot{y} \\
u_3 &= \dot{z} \\
u_4 &= \dot{\theta} \\
u_5 &= \dot{\phi} \\
u_6 &= \dot{\psi} \\
u_7 &= \dot{\theta}_1 \\
u_8 &= \dot{\theta}_2 \\
u_9 &= \dot{\theta}_3 \\
u_{10} &= \dot{\theta}_4
\end{aligned}
\tag{5-1}
$$

where $x,\ y,\ z$ are the coordinates for the center of mass of the center hull, θ is pitch angle (positive bow up), ϕ is roll angle (positive rolling to the right), ψ is yaw angle measured clockwise from North, $\theta_1,\ \theta_2,\ \theta_3,\ \theta_4$ are sponson deflection angles measured positive when the transom of the sponsons deflect upwards, and a dot represents time differentiation. A coordinate system attached to the center hull has the base vectors Fig (5-5) shows schematic drawing of boat with different angles

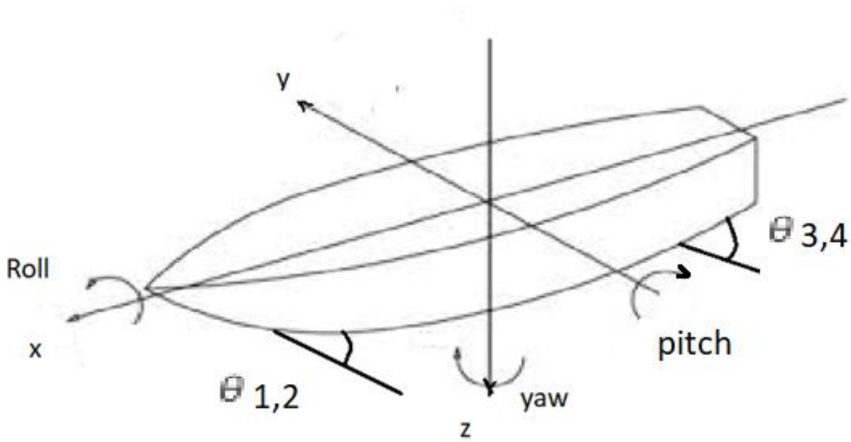


Figure 5-5 Schematic Drawing of Boat with angles

$$\begin{bmatrix} \grave{x} \\ \grave{y} \\ \grave{z} \end{bmatrix} = \begin{bmatrix} \cos\psi & \sin\psi & 0 \\ -\sin\psi & \cos\psi & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \mathrm{R}_3(\psi) \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

$$\begin{bmatrix} \grave{\grave{x}} \\ \grave{\grave{y}} \\ \grave{\grave{z}} \end{bmatrix} = \begin{bmatrix} \cos\theta & 0 & -\sin\theta \\ 0 & 1 & 0 \\ \sin\theta & 0 & \cos\theta \end{bmatrix} \begin{bmatrix} \grave{x} \\ \grave{y} \\ \grave{z} \end{bmatrix} = \mathrm{R}_2(\theta) \begin{bmatrix} \grave{\grave{x}} \\ \grave{\grave{y}} \\ \grave{\grave{z}} \end{bmatrix}$$

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\phi & \sin\phi \\ 0 & -\sin\phi & \cos\phi \end{bmatrix} \begin{bmatrix} \grave{\grave{x}} \\ \grave{\grave{y}} \\ \grave{\grave{z}} \end{bmatrix} = \mathrm{R}_1(\phi) \begin{bmatrix} \grave{\grave{x}} \\ \grave{\grave{y}} \\ \grave{\grave{z}} \end{bmatrix}$$

which combines to give

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = \mathrm{R}_1(\phi)\ \mathrm{R}_2(\theta)\ \mathrm{R}_3(\psi) \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} =$$

$$\begin{bmatrix} \cos\phi\cos\theta & \sin\phi\cos\theta & -\sin\phi \\ -\sin\theta\cos\psi + \cos\theta\sin\phi\sin\psi & \cos\psi\cos\theta + \sin\theta\sin\phi\sin\psi & +\cos\phi\sin\psi \\ \cos\psi\sin\phi\cos\theta + \sin\psi\sin\theta & \sin\theta\sin\phi\cos\psi - \cos\theta\sin\psi & \cos\phi\cos\psi \end{bmatrix}$$

(5-2)

we would re write the same expression using $\boldsymbol{b}_1^0, \boldsymbol{b}_2^0, \boldsymbol{b}_3^0$ which are the base vectors attached to the hull center and $\boldsymbol{n}_1, \boldsymbol{n}_2, \boldsymbol{n}_3$ are the base vectors of fixed frame.

$$\begin{aligned} \boldsymbol{b}_1^0 &= \cos\phi\cos\theta\,\boldsymbol{n}_1 + \sin\phi\cos\theta\,\boldsymbol{n}_2 - \sin\phi\,\boldsymbol{n}_3 \\ \boldsymbol{b}_2^0 &= (-\sin\theta\cos\psi + \cos\theta\sin\phi\sin\psi)\boldsymbol{n}_1 + (\cos\psi\cos\theta + \sin\theta\sin\phi\sin\psi)\boldsymbol{n}_2 \\ &\qquad + \cos\phi\sin\psi\,\boldsymbol{n}_3 \\ \boldsymbol{b}_3^0 &= (\cos\psi\sin\phi\cos\theta + \sin\psi\sin\theta)\boldsymbol{n}_1 + (\sin\theta\sin\phi\cos\psi - \cos\theta\sin\psi)\boldsymbol{n}_2 \\ &\qquad + \cos\phi\cos\psi\,\boldsymbol{n}_3 \end{aligned}$$

A sponson in the present design is attached to the center hull via a revolute (1 degree of freedom rotation) near the bow of the sponsons. These revolutes are parallel to the $\mathbf{b}_2^0$ axis. A coordinate system attached to the front left sponson has the base vectors $\boldsymbol{b}_1^1, \boldsymbol{b}_2^1, \boldsymbol{b}_3^1$

$$\boldsymbol{b}_1^1 = \cos\varphi^1\,\boldsymbol{b}_1^0 + \sin\varphi^1\,\boldsymbol{b}_3^0$$
$$\boldsymbol{b}_2^1 = \boldsymbol{b}_2^0$$
$$\boldsymbol{b}_3^1 = -\sin\varphi^1\,\boldsymbol{b}_1^0 + \cos\varphi^1\,\boldsymbol{b}_3^0$$

(5-3)

Likewise, for the right front and the left and right rear sponsons, respectively:

$$\boldsymbol{b}_1^2 = \cos\varphi^2\,\boldsymbol{b}_1^0 + \sin\varphi^2\,\boldsymbol{b}_3^0$$
$$\boldsymbol{b}_2^2 = \boldsymbol{b}_2^0$$
$$\boldsymbol{b}_3^2 = -\sin\varphi^2\,\boldsymbol{b}_1^0 + \cos\varphi^2\,\boldsymbol{b}_3^0$$

(5-4)

$$\boldsymbol{b}_1^3 = \cos\varphi^3\,\boldsymbol{b}_1^0 + \sin\varphi^3\,\boldsymbol{b}_3^0$$
$$\boldsymbol{b}_2^3 = \boldsymbol{b}_2^0$$
$$\boldsymbol{b}_3^3 = -\sin\varphi^3\,\boldsymbol{b}_1^0 + \cos\varphi^3\,\boldsymbol{b}_3^0$$

(5-5)

$$\boldsymbol{b}_1^4 = \cos\varphi^4\,\boldsymbol{b}_1^0 + \sin\varphi^4\,\boldsymbol{b}_3^0$$
$$\boldsymbol{b}_2^4 = \boldsymbol{b}_2^0$$
$$\boldsymbol{b}_3^4 = -\sin\varphi^4\,\boldsymbol{b}_1^0 + \cos\varphi^4\,\boldsymbol{b}_3^0$$

(5-6)

The angular velocity of the center hull is ($\boldsymbol{\omega}^0$)

$$\boldsymbol{\omega}^0 = \begin{bmatrix}\omega_x\\ \omega_y\\ \omega_z\end{bmatrix} = \begin{bmatrix}\dot{\phi} - \dot{\psi}\sin\theta\\ \dot{\theta}\cos\phi + \dot{\psi}\cos\theta\cos\phi\\ -\dot{\theta}\sin\phi + \dot{\psi}\cos\theta\cos\phi\end{bmatrix} \quad (5\text{-}7)$$

$\boldsymbol{\omega}^0 = (u_5 - u_6\sin\theta)\boldsymbol{n}_1 + (u_4\cos\phi + u_6\cos\theta\sin\phi)\boldsymbol{n}_2 + (-u_4\sin\phi + u_6\cos\theta\cos\phi)\boldsymbol{n}_3$

The angular velocities of sponsons 1-4 are

$$\begin{aligned}\boldsymbol{\omega}^1 &= \boldsymbol{\omega}^0 - u_7\boldsymbol{b}_2^0\\ \boldsymbol{\omega}^2 &= \boldsymbol{\omega}^0 - u_8\boldsymbol{b}_2^0\\ \boldsymbol{\omega}^3 &= \boldsymbol{\omega}^0 - u_9\boldsymbol{b}_2^0\\ \boldsymbol{\omega}^4 &= \boldsymbol{\omega}^0 - u_{10}\boldsymbol{b}_2^0\end{aligned} \quad (5\text{-}8)$$

The revolutes of the front and rear sponsons pass through the points

$$\boldsymbol{x}^{rf} = \boldsymbol{x}^0 + a_1\boldsymbol{b}_1^0 + a_2\boldsymbol{b}_3^0$$

$$\boldsymbol{x}^{rr} = \boldsymbol{x}^0 + a_3\boldsymbol{b}_1^0 + a_4\boldsymbol{b}_3^0 \tag{5-9}$$

respectively, Fig (5-2) shows the positions of the center of mass of the four sponsons are

$$\begin{aligned}
\boldsymbol{x}^1 &= \boldsymbol{x}^0 + a_1\boldsymbol{b}_1^0 + a_2\boldsymbol{b}_3^0 - a_5\boldsymbol{b}_1^1 - a_6\boldsymbol{b}_2^1 + a_7\boldsymbol{b}_3^1\\
\boldsymbol{x}^2 &= \boldsymbol{x}^0 + a_1\boldsymbol{b}_1^0 + a_2\boldsymbol{b}_3^0 - a_5\boldsymbol{b}_1^2 + a_6\boldsymbol{b}_2^2 + a_7\boldsymbol{b}_3^2\\
\boldsymbol{x}^3 &= \boldsymbol{x}^0 + a_3\boldsymbol{b}_1^0 + a_4\boldsymbol{b}_3^0 - a_8\boldsymbol{b}_1^3 - a_9\boldsymbol{b}_2^3 + a_{10}\boldsymbol{b}_3^3\\
\boldsymbol{x}^4 &= \boldsymbol{x}^0 + a_3\boldsymbol{b}_1^0 + a_4\boldsymbol{b}_3^0 - a_8\boldsymbol{b}_1^4 + a_9\boldsymbol{b}_2^4 + a_{10}\boldsymbol{b}_3^4
\end{aligned} \tag{5-10}$$

The positions of the running surfaces, where the water loads are assumed to apply, of the four sponsons are:

$$\begin{aligned}
\boldsymbol{x}^{1w} &= \boldsymbol{x}^0 + a_1\boldsymbol{b}_1^0 + a_2\boldsymbol{b}_3^0 - a_{11}\boldsymbol{b}_1^1 - a_{12}\boldsymbol{b}_2^1 + a_{13}\boldsymbol{b}_3^1\\
\boldsymbol{x}^{2w} &= \boldsymbol{x}^0 + a_1\boldsymbol{b}_1^0 + a_2\boldsymbol{b}_3^0 - a_{11}\boldsymbol{b}_1^1 + a_{12}\boldsymbol{b}_2^1 + a_{13}\boldsymbol{b}_3^1\\
\boldsymbol{x}^{3w} &= \boldsymbol{x}^0 + a_1\boldsymbol{b}_1^0 + a_2\boldsymbol{b}_3^0 - a_{14}\boldsymbol{b}_1^1 - a_{15}\boldsymbol{b}_2^1 + a_{16}\boldsymbol{b}_3^1\\
\boldsymbol{x}^{4w} &= \boldsymbol{x}^0 + a_1\boldsymbol{b}_1^0 + a_2\boldsymbol{b}_3^0 - a_{14}\boldsymbol{b}_1^1 + a_{15}\boldsymbol{b}_2^1 + a_{16}\boldsymbol{b}_3^1
\end{aligned} \tag{5-11}$$

The linear velocities of the center of mass of the center hull and the four sponsons are:

$$\begin{aligned}
\dot{\boldsymbol{x}}^0 &= \dot{x}_1^0\boldsymbol{n}_1 + \dot{x}_2^0\boldsymbol{n}_2 + \dot{x}_3^0\boldsymbol{n}_3 = u_1\boldsymbol{n}_1 + u_2\boldsymbol{n}_2 + u_3\boldsymbol{n}_3\\
\dot{\boldsymbol{x}}^1 &= \dot{\boldsymbol{x}}^0 + \boldsymbol{\omega}^0 \times (a_1\boldsymbol{b}_1^0 + a_2\boldsymbol{b}_3^0) + (-u_7\boldsymbol{b}_2^0) \times (-a_{11}\boldsymbol{b}_1^1 - a_{12}\boldsymbol{b}_2^1 + a_{13}\boldsymbol{b}_3^1)\\
\dot{\boldsymbol{x}}^2 &= \dot{\boldsymbol{x}}^0 + \boldsymbol{\omega}^0 \times (a_1\boldsymbol{b}_1^0 + a_2\boldsymbol{b}_3^0) + (-u_8\boldsymbol{b}_2^0) \times (-a_5\boldsymbol{b}_1^2 + a_6\boldsymbol{b}_2^2 + a_7\boldsymbol{b}_3^2)\\
\dot{\boldsymbol{x}}^3 &= \dot{\boldsymbol{x}}^0 + \boldsymbol{\omega}^0 \times (a_3\boldsymbol{b}_1^0 + a_4\boldsymbol{b}_3^0) + (-u_9\boldsymbol{b}_2^0) \times (-a_8\boldsymbol{b}_1^3 - a_9\boldsymbol{b}_2^3 + a_{10}\boldsymbol{b}_3^3)\\
\dot{\boldsymbol{x}}^4 &= \dot{\boldsymbol{x}}^0 + \boldsymbol{\omega}^0 \times (a_3\boldsymbol{b}_1^0 + a_4\boldsymbol{b}_3^0) + (-u_{10}\boldsymbol{b}_2^0) \times (-a_8\boldsymbol{b}_1^4 + a_9\boldsymbol{b}_2^4 + a_{10}\boldsymbol{b}_3^4)
\end{aligned}$$

(5-12)

The linear accelerations of the center of mass of center of hull is:

$$aH = \dot{u}_1\boldsymbol{b}_1^0 + \dot{u}_2\boldsymbol{b}_2^0 + \dot{u}_3\boldsymbol{b}_3^0 \tag{5-13}$$

The angular accelerations of center of mass of center of hull

$$\alpha s_1 = \alpha H + \alpha s_1 H + \boldsymbol{\omega}^0 \times (-u_7\mathbf{b}_2^0)$$

$$\alpha s_2 = \alpha H + \alpha s_2 H + \boldsymbol{\omega}^0 \times (-u_8\mathbf{b}_2^0)$$

$$\alpha s_3 = \alpha H + \alpha s_3 H + \boldsymbol{\omega}^0 \times (-u_9\mathbf{b}_2^0)$$

$$\alpha s_4 = \alpha H + \alpha s_4 H + \boldsymbol{\omega}^0 \times (-u_{10}\mathbf{b}_2^0) \tag{5-14}$$

Linear acceleration of sponsons relative to global frame:

$$as_1 = aH + \alpha s_1 \times \boldsymbol{x}^1 + \boldsymbol{\omega}^1 \times (\boldsymbol{\omega}^1 \times \boldsymbol{x}^1)$$

$$as_2 = aH + \alpha s_2 \times \mathbf{x}^2 + \boldsymbol{\omega}^2 \times (\boldsymbol{\omega}^2 \times \mathbf{x}^2)$$

$$as_3 = aH + \alpha s_3 \times \mathbf{x}^3 + \boldsymbol{\omega}^3 \times (\boldsymbol{\omega}^3 \times \mathbf{x}^3)$$

$$as_4 = aH + \alpha s_4 \times \mathbf{x}^4 + \boldsymbol{\omega}^4 \times (\boldsymbol{\omega}^4 \times \mathbf{x}^4) \qquad (5\text{-}15)$$

Construction of partial velocity table for each sponson for example

Linear velocity for first sponson $\vec{v}_1{}^{B1}$

Linear velocity for second sponson $\vec{v}_1{}^{B2}$

Linear velocity for third sponson $\vec{v}_1{}^{B3}$

Linear velocity for fourth sponson $\vec{v}_1{}^{B4}$

Table 3 partial derivative of generalized speed

Generalized Speeds (u_r)	$\vec{\boldsymbol{v}}_{\boldsymbol{r}}{}^{\boldsymbol{A}}$	$\vec{\boldsymbol{v}}_{\boldsymbol{r}}{}^{\boldsymbol{B}}$	${}^N\vec{\omega}_r{}^A$	${}^N\vec{\omega}_r{}^B$
r = 1	$\vec{\boldsymbol{v}}_{\boldsymbol{1}}{}^{\boldsymbol{A}}$	$\vec{\boldsymbol{v}}_{\boldsymbol{1}}{}^{\boldsymbol{B}}$	$\vec{\boldsymbol{\omega}}_{\boldsymbol{1}}{}^{\boldsymbol{A}}$	$\vec{\boldsymbol{\omega}}_{\boldsymbol{1}}{}^{\boldsymbol{B}}$
r = 2	$\vec{\boldsymbol{v}}_{\boldsymbol{2}}{}^{\boldsymbol{A}}$	$\vec{\boldsymbol{v}}_{\boldsymbol{2}}{}^{\boldsymbol{B}}$	$\vec{\boldsymbol{\omega}}_{\boldsymbol{2}}{}^{\boldsymbol{A}}$	$\vec{\boldsymbol{\omega}}_{\boldsymbol{2}}{}^{\boldsymbol{B}}$
r=3	$\vec{\boldsymbol{v}}_{\boldsymbol{3}}{}^{\boldsymbol{A}}$	$\vec{\boldsymbol{v}}_{\boldsymbol{3}}{}^{\boldsymbol{B}}$	$\vec{\boldsymbol{\omega}}_{\boldsymbol{3}}{}^{\boldsymbol{A}}$	$\vec{\boldsymbol{\omega}}_{\boldsymbol{3}}{}^{\boldsymbol{B}}$
r=4	$\vec{\boldsymbol{v}}_{\boldsymbol{4}}{}^{\boldsymbol{A}}$	$\vec{\boldsymbol{v}}_{\boldsymbol{4}}{}^{\boldsymbol{B}}$	$\vec{\boldsymbol{\omega}}_{\boldsymbol{4}}{}^{\boldsymbol{A}}$	$\vec{\boldsymbol{\omega}}_{\boldsymbol{4}}{}^{\boldsymbol{B}}$
r=5	$\vec{\boldsymbol{v}}_{\boldsymbol{5}}{}^{\boldsymbol{A}}$	$\vec{\boldsymbol{v}}_{\boldsymbol{5}}{}^{\boldsymbol{B}}$	$\vec{\boldsymbol{\omega}}_{\boldsymbol{5}}{}^{\boldsymbol{A}}$	$\vec{\boldsymbol{\omega}}_{\boldsymbol{5}}{}^{\boldsymbol{B}}$
r=6	$\vec{\boldsymbol{v}}_{\boldsymbol{6}}{}^{\boldsymbol{A}}$	$\vec{\boldsymbol{v}}_{\boldsymbol{6}}{}^{\boldsymbol{B}}$	$\vec{\boldsymbol{\omega}}_{\boldsymbol{6}}{}^{\boldsymbol{A}}$	$\vec{\boldsymbol{\omega}}_{\boldsymbol{6}}{}^{\boldsymbol{B}}$
r=7	$\vec{\boldsymbol{v}}_{\boldsymbol{7}}{}^{\boldsymbol{A}}$	$\vec{\boldsymbol{v}}_{\boldsymbol{7}}{}^{\boldsymbol{B}}$	$\vec{\boldsymbol{\omega}}_{\boldsymbol{7}}{}^{\boldsymbol{A}}$	$\vec{\boldsymbol{\omega}}_{\boldsymbol{7}}{}^{\boldsymbol{B}}$
r=8	$\vec{\boldsymbol{v}}_{\boldsymbol{8}}{}^{\boldsymbol{A}}$	$\vec{\boldsymbol{v}}_{\boldsymbol{8}}{}^{\boldsymbol{B}}$	$\vec{\boldsymbol{\omega}}_{\boldsymbol{8}}{}^{\boldsymbol{A}}$	$\vec{\boldsymbol{\omega}}_{\boldsymbol{8}}{}^{\boldsymbol{B}}$
r=9	$\vec{\boldsymbol{v}}_{\boldsymbol{9}}{}^{\boldsymbol{A}}$	$\vec{\boldsymbol{v}}_{\boldsymbol{9}}{}^{\boldsymbol{B}}$	$\vec{\boldsymbol{\omega}}_{\boldsymbol{9}}{}^{\boldsymbol{A}}$	$\vec{\boldsymbol{\omega}}_{\boldsymbol{9}}{}^{\boldsymbol{B}}$
r=10	$\vec{\boldsymbol{v}}_{\boldsymbol{10}}{}^{\boldsymbol{A}}$	$\vec{\boldsymbol{v}}_{\boldsymbol{10}}{}^{\boldsymbol{B}}$	$\vec{\boldsymbol{\omega}}_{\boldsymbol{10}}{}^{\boldsymbol{A}}$	$\vec{\boldsymbol{\omega}}_{\boldsymbol{10}}{}^{\boldsymbol{B}}$

For hull linear velocity $\qquad \vec{v}_1{}^A = \frac{\partial \dot{x}^0}{\partial u_1}$

For first sponson linear velocity $\qquad \vec{v}_{1,}{}^{B1} = \frac{\partial \dot{x}^1}{\partial u_1}$

For second sponson linear velocity $\qquad \overrightarrow{v^N}_1{}^{B2} = \frac{\dot{x}^2}{\partial u_1}$

For third sponson linear velocity $\qquad \overrightarrow{v^N}_1{}^{B3} = \frac{\dot{x}^3}{\partial u_1}$

For fourth sponson linear velocity $\qquad \overrightarrow{v^N}_1{}^{B4} = \frac{\dot{x}^4}{\partial u_1}$

For angular velocity for hull

$$\vec{\omega}_1{}^A = \frac{\partial \boldsymbol{\omega}^0}{\partial u_1}$$

For first sponson angular velocity

$$\vec{\omega}_1^{\,B1} = \frac{\partial \boldsymbol{\omega}^1}{\partial u_1}$$

For second sponson angular velocity

$$\vec{\omega}_1^{\,B2} = \frac{\partial \boldsymbol{\omega}^2}{\partial u_1}$$

For third sponson angular velocity

$$\vec{\omega}_1^{\,B3} = \frac{\partial \boldsymbol{\omega}^3}{\partial u_1}$$

For fourth sponson angular velocity

$$\vec{\omega}_1^{\,B4} = \frac{\partial \boldsymbol{\omega}^4}{\partial u_1}$$

Assume external force $F\chi\boldsymbol{n}_3$

M1=$(F_1\chi\boldsymbol{n}_3) \times (\boldsymbol{x}^{1w} - \boldsymbol{x}^{rf})$
M2=$(F_2\chi\boldsymbol{n}_3) \times (\boldsymbol{x}^{2w} - \boldsymbol{x}^{rf})$

M3=$(F_3\chi\boldsymbol{n}_3) \times (\boldsymbol{x}^{3w} - \boldsymbol{x}^{rr})$

M4=$(F_4\chi\boldsymbol{n}_3) \times (\boldsymbol{x}^{4w} - \boldsymbol{x}^{rr})$ (5-16)

M1 is the moment applied on first sponson

M2 is the moment applied on second sponson

M3 is the moment applied on third sponson

M4 is the moment applied on fourth sponson

$ks_1 = k_1\chi\varphi^1$

$ks_2 = k_2\chi\varphi^2$

$ks_3 = k_3\chi\varphi^3$

$ks_4 = k_4\chi\varphi^4$

$D_1 = C_1\chi\varphi^1$

$D_2 = C_2\chi\varphi^2$

$D_3 = C_3\chi\varphi^3$

$D_4 = C_4\chi\varphi^4$

$ks_{1,2,3,4} is\ spring\ moment\ on\ first\ sponson, second\ , third\ and\ fourth\ sponsons$

$D_1\ is\ damping\ moment\ \ on\ first, second, third\ and\ fourth\ sponsons$

Generalized External Forces:

where the generalized active force, F_r, is defined as:

$$F_r = \sum_r \left(\vec{F}_A \cdot {}^N\vec{v}_r{}^A + \vec{T}_A \cdot {}^N\vec{\omega}_r{}^A + \vec{F}_B \cdot {}^N\vec{v}_r{}^B + \vec{T}_B \cdot {}^N\vec{\omega}_r{}^B\right)$$

F1 = $((-Mg\chi\boldsymbol{n}_3) + (F_1\chi\boldsymbol{n}_3) + (F_2\chi\boldsymbol{n}_3) + (F_3\chi\boldsymbol{n}_3) + (F_4\chi\boldsymbol{n}_3)).\vec{v}_1{}^A +$
$(-mg\chi\boldsymbol{n}_3).\vec{v}_1{}^{B1}(\mathrm{M1}.\vec{\omega}_1{}^{B1}) + (ks_1.\vec{\omega}_1{}^{B1}) + (D_1.\vec{\omega}_1{}^{B1}) + (-mg\chi\boldsymbol{n}_3).\vec{v}_1{}^{B2} + (\mathrm{M2}.\vec{\omega}_1{}^{B2} +$
$\left(ks_2.\vec{\omega}_1{}^{B2}\right) + \left(D_2.\vec{\omega}_1{}^{B2}\right) + \quad (-mxg\chi\boldsymbol{n}_3).\vec{v}_1{}^{B3} + \left(\mathrm{M3}.\vec{\omega}_1{}^{B3}\right) + \left(ks_3.\vec{\omega}_1{}^{B3}\right) +$
$(-mxg\chi\boldsymbol{n}_3).\vec{v}_1{}^{B4} + \left(\mathrm{M4}.\vec{\omega}_1{}^{B4}\right) + \left(ks_4.\vec{\omega}_1{}^{B4}\right) + \left(D_4.\vec{\omega}_1{}^{B4}\right)$
(5-17)

Similarly derive the external force equations F_1 to F_{10}

Generalized Inertia Force:

generalized inertia force, FI_r, is defined as:

$$\boldsymbol{FI_r} = \sum_r \left(-\boldsymbol{M} \cdot \vec{\boldsymbol{a}}^{\boldsymbol{A}} \cdot \vec{\boldsymbol{v}}_{\boldsymbol{r}}{}^{\boldsymbol{A}} - \left(\vec{\boldsymbol{\alpha}}^{\boldsymbol{A}} \cdot \vec{\vec{\boldsymbol{I}}} + \vec{\boldsymbol{\omega}}^{\boldsymbol{A}} \times \vec{\vec{\boldsymbol{I}}} \cdot \vec{\boldsymbol{\omega}}^{\boldsymbol{A}}\right) \cdot \vec{\boldsymbol{\omega}}_{\boldsymbol{r}}{}^{\boldsymbol{A}} - \boldsymbol{m} \cdot \vec{\boldsymbol{a}}^{\boldsymbol{B}} \cdot \vec{\boldsymbol{v}}_{\boldsymbol{r}}{}^{\boldsymbol{B}} - \left(\vec{\boldsymbol{\alpha}}^{\boldsymbol{B}} \cdot \vec{\vec{\boldsymbol{I}}} + \vec{\boldsymbol{\omega}}^{\boldsymbol{B}} \times \vec{\vec{\boldsymbol{I}}} \cdot \vec{\boldsymbol{\omega}}^{\boldsymbol{B}}\right) \cdot \vec{\boldsymbol{\omega}}_{\boldsymbol{r}}{}^{\boldsymbol{B}}\right)$$

Moment of inertia of the hull

$$I = \begin{bmatrix} I_{11} & 0 & 0 \\ 0 & I_{22} & 0 \\ 0 & 0 & I_{33} \end{bmatrix}$$

Moment of inertia of the sponson

$$Is = \begin{bmatrix} Is_{11} & 0 & 0 \\ 0 & Is_{22} & 0 \\ 0 & 0 & Is_{33} \end{bmatrix}$$

$$\mathrm{FI1} = (-M\chi\mathrm{aH})\vec{v}_{\mathbf{1}}{}^{A} - (\mathrm{alfaH.I}).\vec{\omega}_{\mathbf{1}}{}^{A} + (-m\chi as_1).\vec{v}_{\mathbf{1}}{}^{B1} + (-m\chi as_2).\vec{v}_{\mathbf{1}}{}^{B2} + (-m\chi as_3).\vec{v}_{\mathbf{1}}{}^{B3} + (-m\chi as_4).\vec{v}_{\mathbf{1}}{}^{B4} - (\alpha s_1.\mathrm{Is}).\vec{\omega}_{\mathbf{1}}{}^{B1} - (\alpha s_2.\mathrm{Is}).\vec{\omega}_{\mathbf{1}}{}^{B2} - (\alpha s_3.\mathrm{Ims}).\vec{\omega}_{\mathbf{1}}{}^{B3} - (\alpha s_4.\mathrm{Is}).\vec{\omega}_{\mathbf{1}}{}^{B4} \tag{5-18}$$

$$\mathrm{FI2} = (-M\chi\mathrm{aH})\vec{v}_{\mathbf{2}}{}^{A} - (\mathrm{alfaH.I}).\vec{\omega}_{\mathbf{2}}{}^{A} + (-m\chi as_1).\vec{v}_{\mathbf{2}}{}^{B1} + (-m\chi as_2).\vec{v}_{\mathbf{2}}{}^{B2} + (-m\chi as_3).\vec{v}_{\mathbf{2}}{}^{B3} + (-m\chi as_4).\vec{v}_{\mathbf{2}}{}^{B4} - (\alpha s_1.\mathrm{Is}).\vec{\omega}_{\mathbf{2}}{}^{B1} - (\alpha s_2.\mathrm{Is}).\vec{\omega}_{\mathbf{2}}{}^{B2} - (\alpha s_3.\mathrm{Ims}).\vec{\omega}_{\mathbf{2}}{}^{B3} - (\alpha s_4.\mathrm{Is}).\vec{\omega}_{\mathbf{2}}{}^{B4}$$

$$\mathrm{FI3} = (-M\chi\mathrm{aH})\vec{v}_{\mathbf{3}}{}^{A} - (\mathrm{alfaH.I}).\vec{\omega}_{\mathbf{3}}{}^{A} + (-m\chi as_1).\vec{v}_{\mathbf{3}}{}^{B1} + (-m\chi as_2).\vec{v}_{\mathbf{3}}{}^{B2} + (-m\chi as_3).\vec{v}_{\mathbf{3}}{}^{B3} + (-m\chi as_4).\vec{v}_{\mathbf{3}}{}^{B4} - (\alpha s_1.\mathrm{Is}).\vec{\omega}_{\mathbf{3}}{}^{B1} - (\alpha s_2.\mathrm{Is}).\vec{\omega}_{\mathbf{3}}{}^{B2} - (\alpha s_3.\mathrm{Ims}).\vec{\omega}_{\mathbf{3}}{}^{B3} - (\alpha s_4.\mathrm{Is}).\vec{\omega}_{\mathbf{3}}{}^{B4}$$

$$\mathrm{FI4} = (-M\chi\mathrm{aH})\vec{v}_{\mathbf{4}}{}^{A} - (\mathrm{alfaH.I}).\vec{\omega}_{\mathbf{4}}{}^{A} + (-m\chi as_1).\vec{v}_{\mathbf{4}}{}^{B1} + (-m\chi as_2).\vec{v}_{\mathbf{4}}{}^{B2} + (-m\chi as_3).\vec{v}_{\mathbf{4}}{}^{B3} + (-m\chi as_4).\vec{v}_{\mathbf{4}}{}^{B4} - (\alpha s_1.\mathrm{Is}).\vec{\omega}_{\mathbf{4}}{}^{B1} - (\alpha s_2.\mathrm{Is}).\vec{\omega}_{\mathbf{4}}{}^{B2} - (\alpha s_3.\mathrm{Ims}).\vec{\omega}_{\mathbf{4}}{}^{B3} - (\alpha s_4.\mathrm{Is}).\vec{\omega}_{\mathbf{4}}{}^{B4}$$

$$\mathrm{FI5} = (-M\chi\mathrm{aH})\vec{v}_{\mathbf{5}}{}^{A} - (\mathrm{alfaH.I}).\vec{\omega}_{\mathbf{5}}{}^{A} + (-m\chi as_1).\vec{v}_{\mathbf{5}}{}^{B1} + (-m\chi as_2).\vec{v}_{\mathbf{5}}{}^{B2} + (-m\chi as_3).\vec{v}_{\mathbf{5}}{}^{B3} + (-m\chi as_4).\vec{v}_{\mathbf{5}}{}^{B4} - (\alpha s_1.\mathrm{Is}).\vec{\omega}_{\mathbf{5}}{}^{B1} - (\alpha s_2.\mathrm{Is}).\vec{\omega}_{\mathbf{5}}{}^{B2} - (\alpha s_3.\mathrm{Ims}).\vec{\omega}_{\mathbf{5}}{}^{B3} - (\alpha s_4.\mathrm{Is}).\vec{\omega}_{\mathbf{5}}{}^{B4}$$

$$\mathrm{FI6} = (-M\chi\mathrm{aH})\vec{v}_{\mathbf{6}}{}^{A} - (\mathrm{alfaH.I}).\vec{\omega}_{\mathbf{6}}{}^{A} + (-m\chi as_1).\vec{v}_{\mathbf{6}}{}^{B1} + (-m\chi as_2).\vec{v}_{\mathbf{6}}{}^{B2} + (-m\chi as_3).\vec{v}_{\mathbf{6}}{}^{B3} + (-m\chi as_4).\vec{v}_{\mathbf{6}}{}^{B4} - (\alpha s_1.\mathrm{Is}).\vec{\omega}_{\mathbf{6}}{}^{B1} - (\alpha s_2.\mathrm{Is}).\vec{\omega}_{\mathbf{6}}{}^{B2} - (\alpha s_3.\mathrm{Ims}).\vec{\omega}_{\mathbf{6}}{}^{B3} - (\alpha s_4.\mathrm{Is}).\vec{\omega}_{\mathbf{6}}{}^{B4}$$

$$\mathrm{FI7} = (-M\chi\mathrm{aH})\vec{v}_{\mathbf{7}}{}^{A} - (\mathrm{alfaH.I}).\vec{\omega}_{\mathbf{7}}{}^{A} + (-m\chi as_1).\vec{v}_{\mathbf{7}}{}^{B1} + (-m\chi as_2).\vec{v}_{\mathbf{7}}{}^{B2} + (-m\chi as_3).\vec{v}_{\mathbf{7}}{}^{B3} + (-m\chi as_4).\vec{v}_{\mathbf{7}}{}^{B4} - (\alpha s_1.\mathrm{Is}).\vec{\omega}_{\mathbf{7}}{}^{B1} - (\alpha s_2.\mathrm{Is}).\vec{\omega}_{\mathbf{7}}{}^{B2} - (\alpha s_3.\mathrm{Ims}).\vec{\omega}_{\mathbf{7}}{}^{B3} - (\alpha s_4.\mathrm{Is}).\vec{\omega}_{\mathbf{7}}{}^{B4}$$

$$\mathrm{FI8} = (-M\chi\mathrm{aH})\vec{v}_{\mathbf{8}}{}^{A} - (\mathrm{alfaH.I}).\vec{\omega}_{\mathbf{8}}{}^{A} + (-m\chi as_1).\vec{v}_{\mathbf{8}}{}^{B1} + (-m\chi as_2).\vec{v}_{\mathbf{8}}{}^{B2} + (-m\chi as_3).\vec{v}_{\mathbf{8}}{}^{B3} + (-m\chi as_4).\vec{v}_{\mathbf{8}}{}^{B4} - (\alpha s_1.\mathrm{Is}).\vec{\omega}_{\mathbf{8}}{}^{B1} - (\alpha s_2.\mathrm{Is}).\vec{\omega}_{\mathbf{8}}{}^{B2} - (\alpha s_3.\mathrm{Ims}).\vec{\omega}_{\mathbf{8}}{}^{B3} - (\alpha s_4.\mathrm{Is}).\vec{\omega}_{\mathbf{8}}{}^{B4}$$

$$\mathrm{FI9} = (-M\chi \mathrm{aH})\vec{v}_{\mathbf{9}}{}^{A} - (\mathrm{alfaH.I}).\vec{\omega}_{\mathbf{9}}{}^{A} + (-m\chi as_1).\vec{v}_{\mathbf{9}}{}^{B1} + (-m\chi as_2).\vec{v}_{\mathbf{9}}{}^{B2} + (-m\chi as_3).\vec{v}_{\mathbf{9}}{}^{B3} + (-m\chi as_4).\vec{v}_{\mathbf{9}}{}^{B4} - (\alpha s_1.\mathrm{Is}).\vec{\omega}_{\mathbf{9}}{}^{B1} - (\alpha s_2.\mathrm{Is}).\vec{\omega}_{\mathbf{9}}{}^{B2} - (\alpha s_3.\mathrm{Ims}).\vec{\omega}_{\mathbf{9}}{}^{B3} - (\alpha s_4.\mathrm{Is}).\vec{\omega}_{\mathbf{9}}{}^{B4}$$

$$\mathrm{FI10} = (-M\chi \mathrm{aH})\vec{v}_{\mathbf{10}}{}^{A} - (\mathrm{alfaH.I}).\vec{\omega}_{\mathbf{10}}{}^{A} + (-m\chi as_1).\vec{v}_{\mathbf{10}}{}^{B1} + (-m\chi as_2).\vec{v}_{\mathbf{10}}{}^{B2} + (-m\chi as_3).\vec{v}_{\mathbf{10}}{}^{B3} + (-m\chi as_4).\vec{v}_{\mathbf{10}}{}^{B4} - (\alpha s_1.\mathrm{Is}).\vec{\omega}_{\mathbf{10}}{}^{B1} - (\alpha s_2.\mathrm{Is}).\overrightarrow{{}^{N}\omega_{\mathbf{10}}}{}^{B2} - (\alpha s_3.\mathrm{Ims}).\vec{\omega}_{\mathbf{10}}{}^{B3} - (\alpha s_4.\mathrm{Is}).\vec{\omega}_{\mathbf{10}}{}^{B4}$$

Assemble $F_r + FI_r = 0$

$\mathrm{F1} + \mathrm{FI1} = 0$

$\mathrm{F2} + \mathrm{FI2} = 0$

$\mathrm{F3} + \mathrm{FI3} = 0$

$\mathrm{F4} + \mathrm{FI4} = 0$

$\mathrm{F5} + \mathrm{FI5} = 0$

$\mathrm{F6} + \mathrm{FI6} = 0$

$\mathrm{F7} + \mathrm{FI7} = 0$

$\mathrm{F8} + \mathrm{FI8} = 0$

$\mathrm{F9} + \mathrm{FI9} = 0$

$\mathrm{F10} + \mathrm{FI10} = 0$ (5-19)

Which could be written in the form:

$$\begin{bmatrix} & \cdots & \\ \vdots & \boldsymbol{LHS\ COFFICENT} & \vdots \\ & \cdots & \end{bmatrix} \begin{bmatrix} \dot{\boldsymbol{u}}_{\mathbf{1}} \\ \dot{\boldsymbol{u}}_{\mathbf{2}} \\ \dot{\boldsymbol{u}}_{\mathbf{3}} \\ \dot{\boldsymbol{u}}_{\mathbf{4}} \\ \dot{\boldsymbol{u}}_{\mathbf{5}} \\ \dot{\boldsymbol{u}}_{\mathbf{6}} \\ \dot{\boldsymbol{u}}_{\mathbf{7}} \\ \dot{\boldsymbol{u}}_{\mathbf{8}} \\ \dot{\boldsymbol{u}}_{\mathbf{9}} \\ \dot{\boldsymbol{u}}_{\mathbf{10}} \end{bmatrix} = \begin{bmatrix} & \cdots & \\ \vdots & \boldsymbol{RHS\ COFFICENT} & \vdots \\ & \cdots & \end{bmatrix} \tag{5-20}$$

Solving the equations using Mathematica model to determine RHS coefficient Matrix, LHS coefficient matrix.

Mathematica model and MatLab code in appendix I.

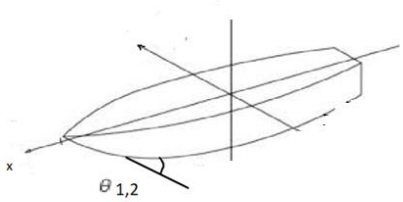
Test parameters

```
M = 1000000;% Hull mass
m1=2; % sponson#1 mass
m2=2; % sponson#2 mass
m3=2; % sponson#3 mass
m4=2; % sponson#4 mass
k1=100; % spring stiffness for first sponson
k2=100; % spring stiffness for second sponson
k3=100; %spring stiffness for third sponson

k4=100; spring stiffness for fourth sponson
c1=10; damping coefficient first sponson
c2=10; spring stiffness for second sponson
c3=10; spring stiffness for third sponson
c4=10; spring stiffness for fourth sponson
a1=10; distance in x direction to front joint
a2=2; distance in y direction to front joint
a3=-10; distance in x direction to rear joint
a4=2; distance in y direction to rear joint
a5=10; The positions of the center of mass of the first
and second sponsons in x direction
a6=10; The positions of the center of mass of the first
and second sponsons in y direction

a7=10; The positions of the center of mass of the first
and second sponsons in z direction
a8=10; The positions of the center of mass of the first
and second sponsons in z direction
a9=10; The positions of the center of mass of the first
and second sponsons in z direction
a10=10; The positions of the center of mass of the
first and second sponsons in z direction
a11=5; water loads are assumed to apply in x direction on
first and second sponsons
a12=5; water loads are assumed to apply in x direction
on first and second sponsons
```

```
a13=5; water loads are assumed to apply in x direction
on first and second sponsons
a14=5; water loads are assumed to apply in x direction
on third and fourth sponsons
a15=5; water loads are assumed to apply in x direction
on third and fourth sponsons
a16=5; water loads are assumed to apply in x direction
on third and fourth sponsons
 F11=100; force applied upward direction on first
sponson
 F22=100; force applied upward direction on second
sponson
 F33=100; force applied upward direction on third
sponson
 F44=100; force applied upward direction on fourth
sponson
IAmx=3; moment of inertia of sponsons
IAmy=3; moment of inertia of sponsons
IAmz=3; moment of inertia of sponsons
IAx=1000000; moment of inertia of hull
IAy=1000000; moment of inertia of hull
IAx=1000000; moment of inertia of hull

g =0;
```

5.1 Simulation results

By apply up word equal forces on front and rear sponons near neglecting the gravity we are expecting sinusoidal wave due to rotational angle of each sponson as shown in figure (5-6), (5-7), (5-8), (5-9)



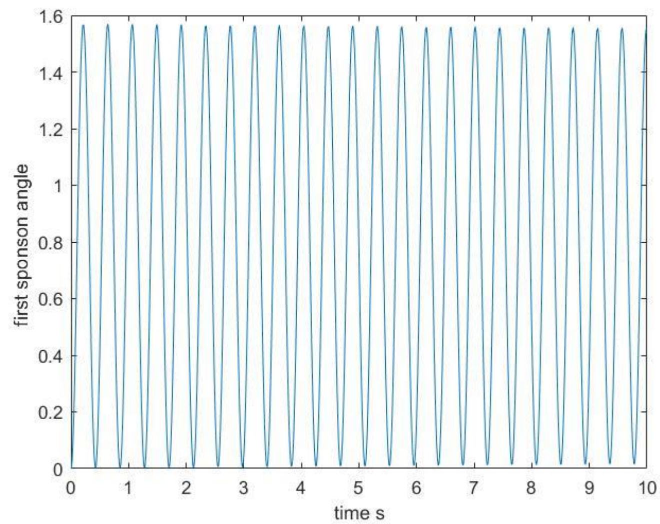


Figure 5-6 First sponson angle

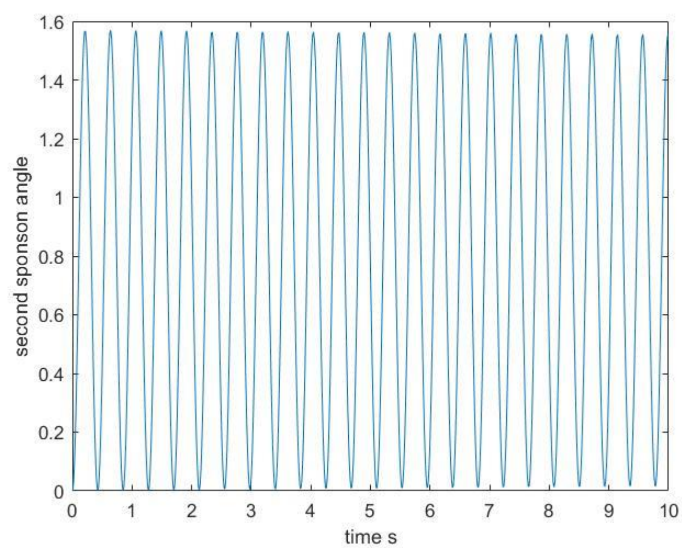
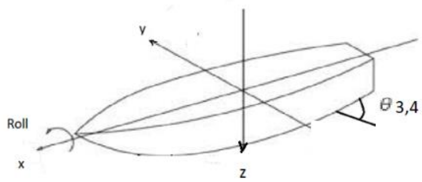


Figure 5-7 Second Sponson Angle



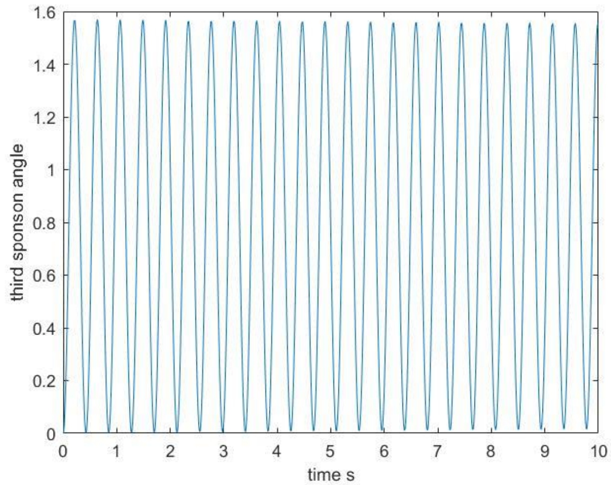


Figure 5-8 Third Sponson Angle

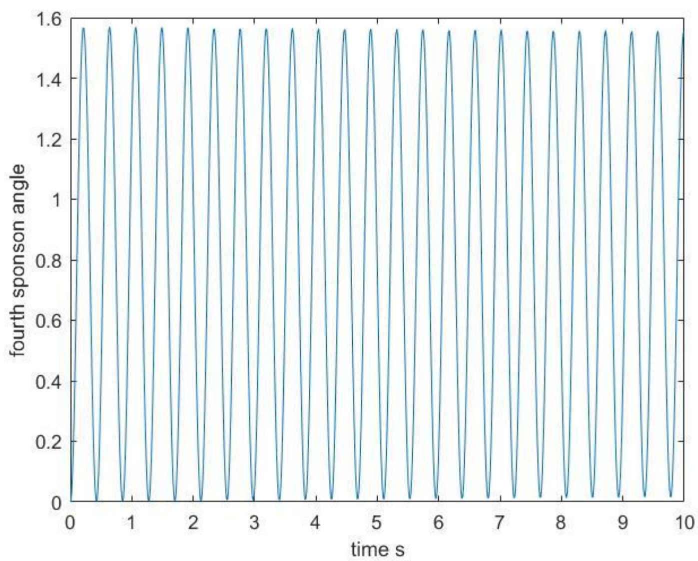


Figure 5-9 Fourth Sponson Angle

Fig (5-10) shows the hull pitch angle behavior

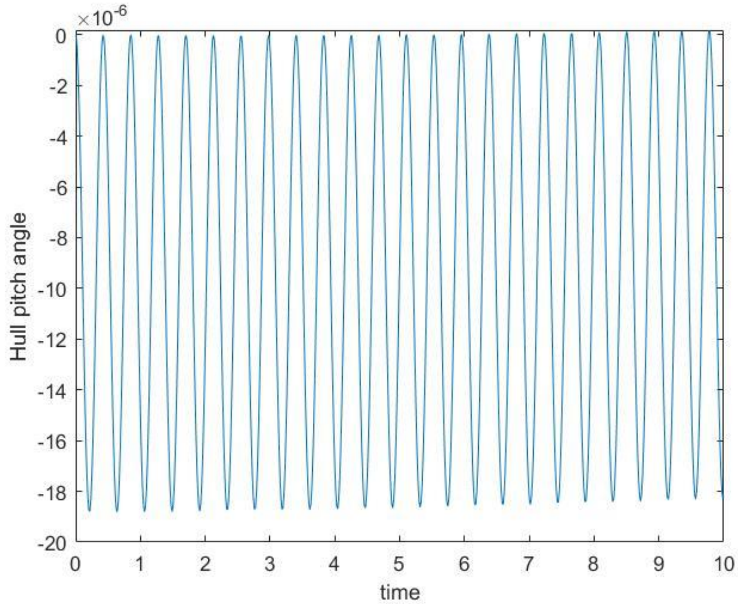


Figure 5-10 Hull pitch Angel

While hull roll and yaw angles show zero change.

The hull movement in z direction due to applied force is shown in Fig (5-11)

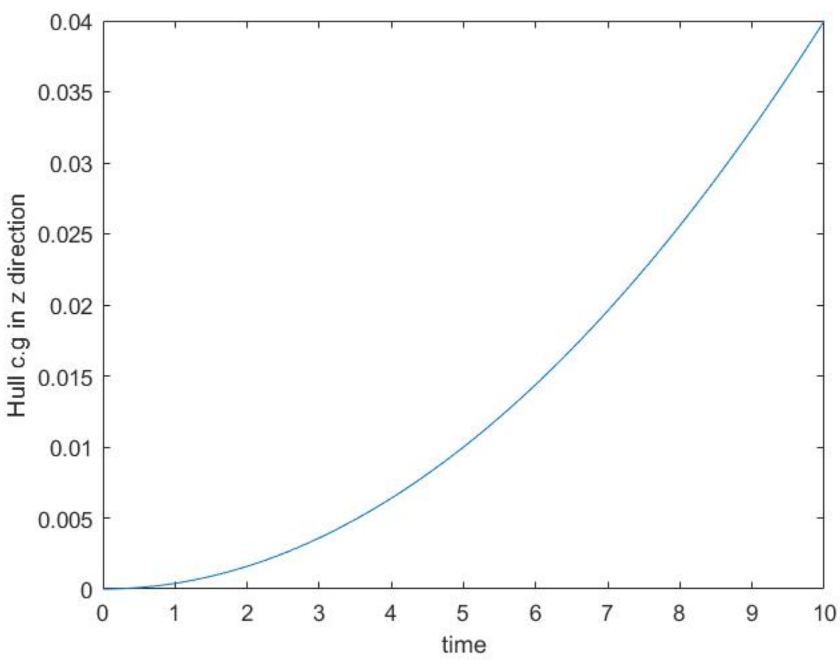


Figure 5-11 Hull z direction

While the boat hull in y direction is zero, Fig (5-12) show the movement of the hull in x direction

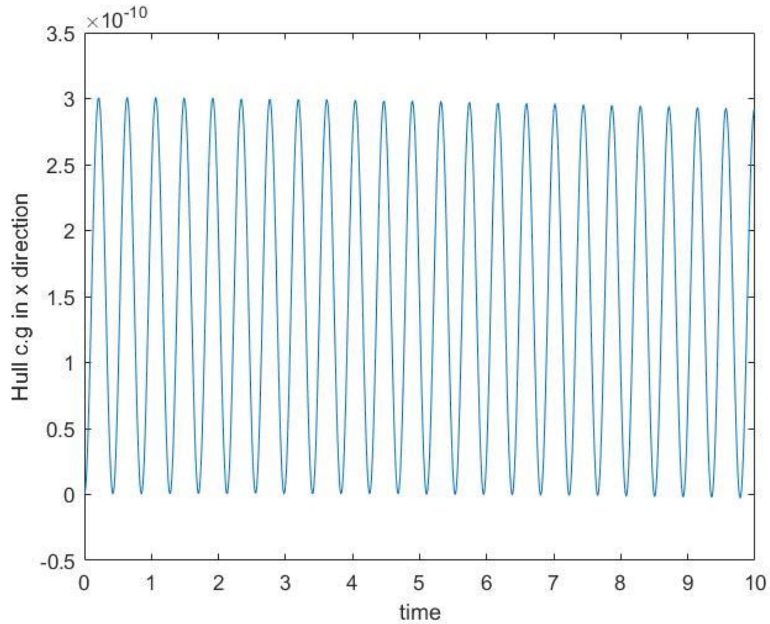
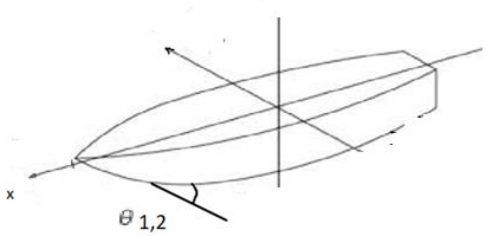


Figure 5-12 Hull in x Direction

Same parameters applied with adding spring and damper for each speonson, the dampingelements reduced the sponsons shock as shown in Fig (5-13), (5-14), (5-15), (5-16)



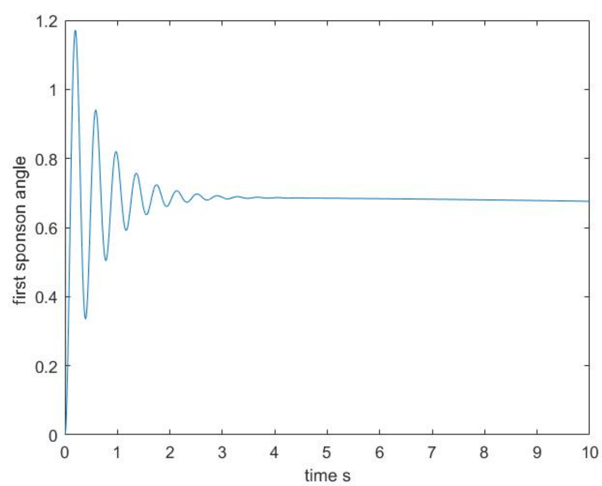


Figure 5-13 First sponson angle

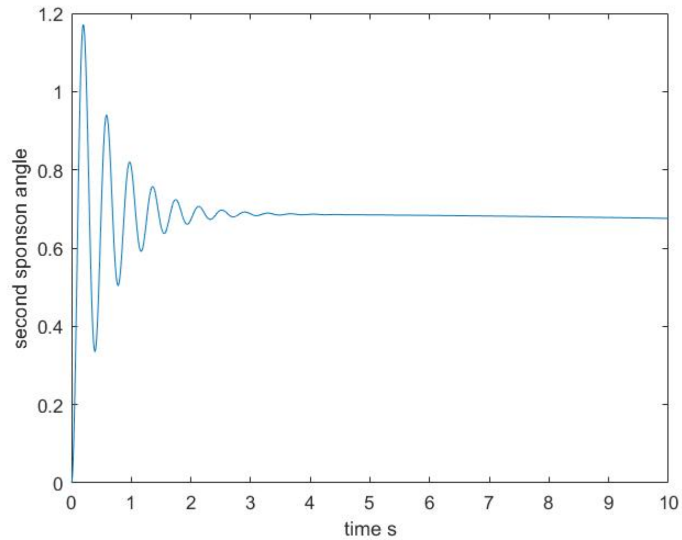


Figure 5-14 Second sponson Angle

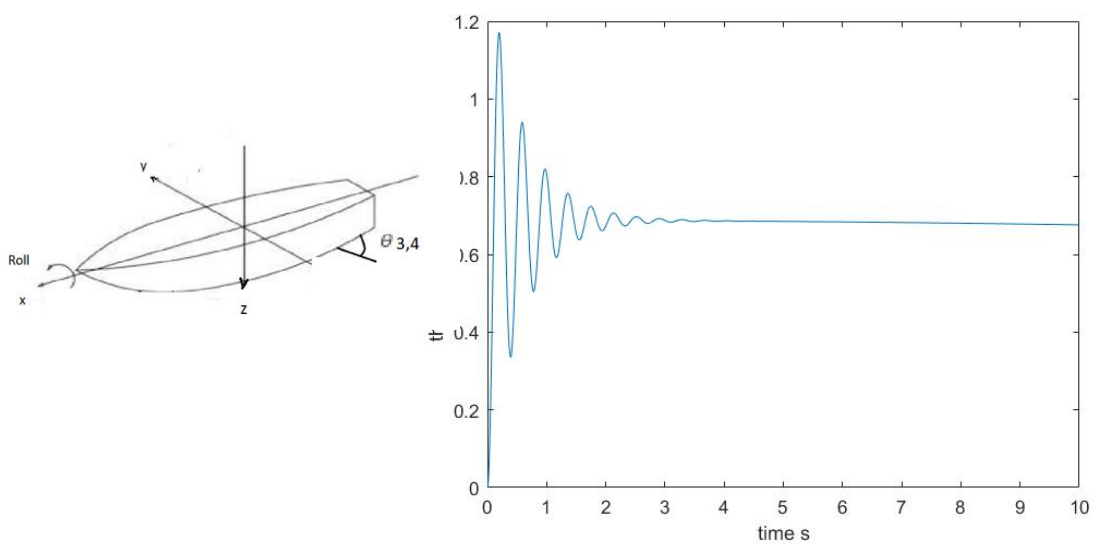


Figure 5-15 Second sponson Angle

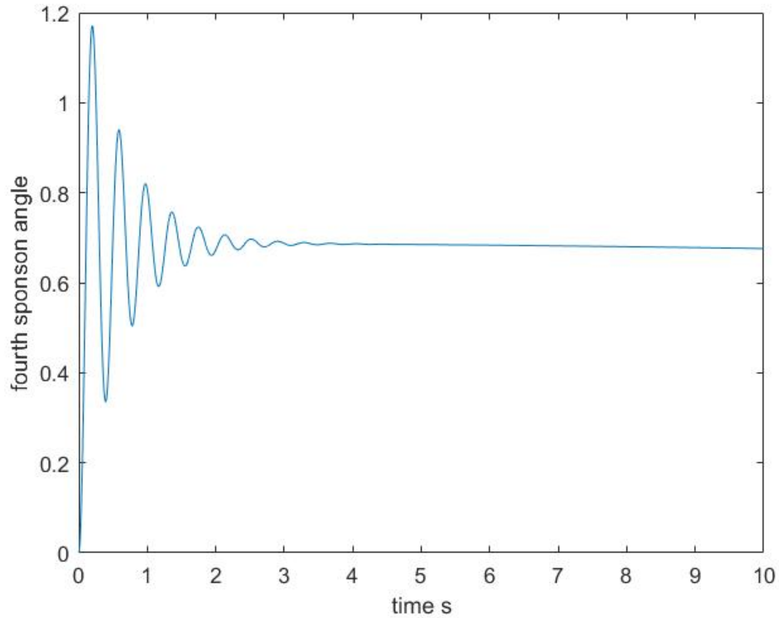
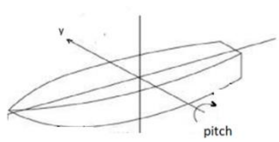


Figure 5-16 Fourth Sponson Angle

Fig (5-17) shows the Hull pitch angle, while roll and pitch angles are zero



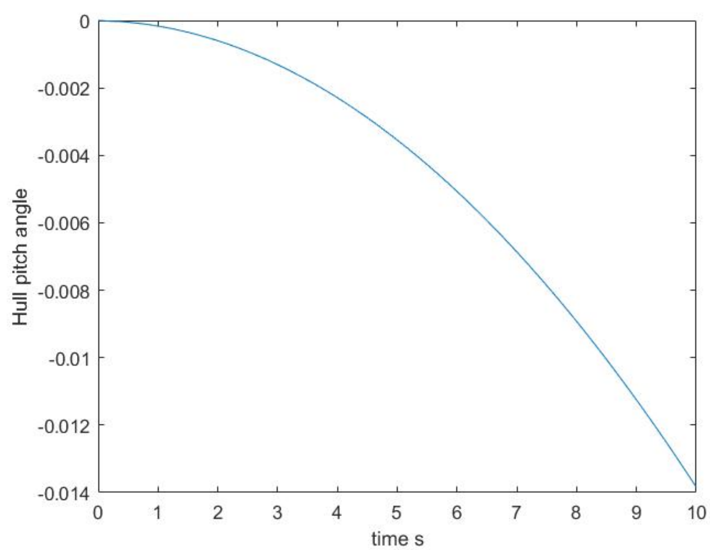


Figure 5-17 Hull pitch angle

Figure (5-18) shows the hull movement in x direction

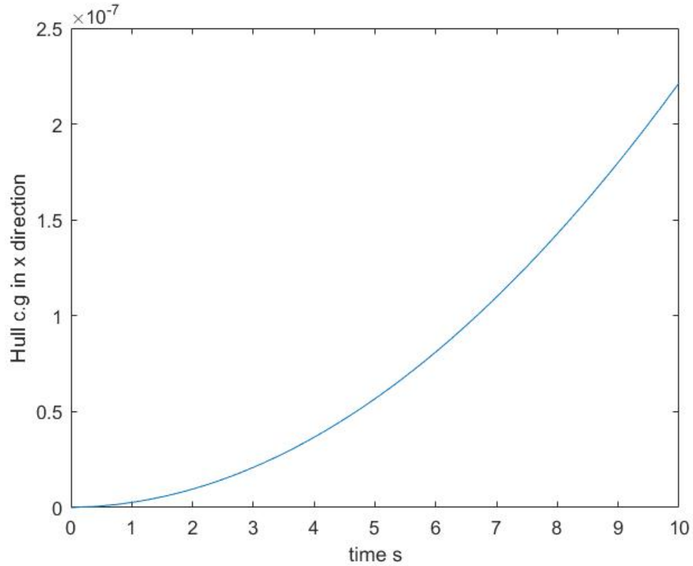


Figure 5-18 Hull Movement in x Direction

The results show reduction of vibration using the shock absorber components.

6 Conclusion and Future Work

An experimental test of the boat with the hinged flap equipped with data acquisition system using different shock absorber parameters is described, using different parameters then peak detection algorithm method used to analyze and compare between different tests.

The study shows reduction of vertical acceleration using the mechanism with specific shock absorber parameters, the obtained vertical acceleration reduction was 5%, knowing that this result based on five testes at same sea state.

The study introduced a 10 DOF dynamic model using Kane's equation of motion for suspension boat consists of main hull and four sponsons patented by Prof. Grenestedt, The model can be used to facilitate choosing the optimum design parameters and damping coefficients.

Recommended Future Work

Running more experimental tests using different suspension geometries, different shock designs, in different sea states to came up with the optimum design parameters.

Scale up to full dimension boat and experimentally test and evaluate the boat behavior in different sea states.

Validate the numerical dynamic simulation by experimentally test small scale of suspension boat and compare the experimental results to simulated one.

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8 Appendices

Appendix A

INTRODUCTION AND DESCRIPTION CHANGES:

Thank you for purchasing the AquaCraft Revolt. We at AquaCraft want the time you spend with your boat to be safe, fun and successful. If for any reason you feel this R/C model is not for you return it to your place of purchase immediately. Your hobby dealer cannot accept returns on any model after fi nal assembly or after your boat has been operated.

AquaCraft products are to be used by ages 14 and over.

TM

All pictures, descriptions, and specifi cations found in this instruction manual are subject to change without notice. AquaCraft maintains no responsibility for inadvertent errors in this manual.

INCLUDED WITH YOUR BOAT:

Revolt FE Mono

Tactic™ TTX240 2.4GHz Transmitter (Performance 2.4GHz Version Only) ABS Molded Boat Stand

PARTS AND TOOLS NEEDED TO COMPLETE AND WORK ON YOUR MODEL:

Radio system of your choice (Receiver Ready) Rx-R™ Version 4 – AA Batteries (FUGP7300 Fuji AA batteries) LiPo Battery pack/s (See Option Parts below LiPo battery Charger (See Option Parts below) Tools and supplies available from your local Hobby Dealer:1.5mm Hex Driver (DTXR0288 Duratrax® 1.5mm Hex Driver)2.5mm Hex Driver (DTXR0290 Duratrax 2.5mm Hex Driver)3mm Hex Driver (DTXR0291 Duratrax 3mm Hex Driver) 5.5mm Nut Driver (DTXR0212 Duratrax 5.5mm Nut Driver) 7mm nut driver (DTXR0216 Duratrax 7mm Nut Driver)4mm Phillips (DTXR0282 Duratrax 4mm Phillips Screw Driver) Bearing oil (MMRC3506

Muchmore™ Bearing Lube)G rimRacer™ Speed Grease (AQUB9500 GrimRacer Speed Grease) Hook and Loop (GPMQ4480 Great Planes® Hook and Loop)

Tools and supplies available from your local hardware or home store.10mm open end wrench12mm open end wrench Water displacer (WD-40®, CRC 6-56® or Corrosion X®)Paper Towel

OPTION PARTS:

AQUB9768 L 45x68 2-Bladed Prop (This prop has great acceleration as well as top speed.)

AQUB9514 GrimRacer Pro Radio Box Tape

AQUB6322 G rimRacer Decal Set (Let 'em know you're ready to race!)

GPMP0751 SafeCharge LiPo bag

Batteries and Chargers:

For your convenience we have listed below a few different battery and charger options. It is also important to note that chargers come in both DC and AC/DC versions. DC chargers require a 12V power supply like a 12V car battery or bench top power supply to power up the charger. AC/DC chargers allow you to plug the charger into a 120V house outlet or DC power supply, therefore making them more convenient for most charging situations. Option 1: This is the easiest option.

Two (2) AQUB9825 GrimRacer LiPo 2S 7.4V 4200mAh 30C

ORTwo (2) AQUB9834 GrimRacer LiPo 2S 7.4V 5000mAh 40C and One (1) DTXP4245 Onyx™ 245 AC/DC Dual Charger W/Balancer Option 2: More advanced but allows slightly better boat handling One (1) AQUB9830 GrimRacer LiPo 2S 14.8V 4200mAh 30C OR One (1) AQUB9840 GrimRacer LiPo 2S 14.8V 5000mAh 40C and One (1) GPMM3155 Great Planes ElectriFly® Triton™ EQ AC/DC Battery Charger

NOTE: When using a single 4S pack, you must reconfi gure the current connector system. We will show you how in the ASSEMBLY section of this manual.

WARRANTY SERVICE:

AquaCraft will warrant your Revolt for 90 days after the purchase from defects in materials or workmanship of original manufacture. AquaCraft, at their option, will repair or replace at no charge, the incorrectly made part. This warranty does not cover damage caused by crash, abuse, misuse, alteration or accident. To return your boat for service you need to provide proof of purchase. Your store receipt or product invoice will suffice.

This warranty gives you specific legal rights and you may also have other rights, which vary from state to state.

Outside USA and Canada, contact local importer for warranty information.

Hobby Services

3002 N. Apollo Drive, Suite 1

Champaign, IL 61822

Attn: Service Department

Phone: (217) 398-0007 9:00 am - 5:00 pm Central Time M-F

E-mail: hobbyservices@hobbico.com

SAFETY PRECUATIONS:

Never, ever attempt to swim after a stalled RC boat. DO NOT get in the water for any reason to retrieve your boat. Your Revolt has flotation added to the interior of the hull and the cowl. They will not sink. To aid you in retrieving a stalled RC boat you can use a fi shing reel with a tennis ball tied to the end of the line. Or better yet, get yourself a small Jon boat so you can row out and pick up your boat. Remember to use a PFD any time you enter your retrieval craft.

Do not touch the propeller anytime the motor is running. Pay equally close attention to items such as loose clothing, shirtsleeves, ties, scarves, long hair or anything that may become entangled in the spinning prop. If your fingers, hands, etc. come in contact with the spinning propeller, you may be severely injured.

➡ The speed and mass of this boat can inflict property damage and severe personal injury if a collision occurs. Never run this boat in the presence of swimmers or where the possibility of collision with people or property exists.

➡ This boat is controlled by radio signals, which are susceptible to possible interference from RF sources. It is a good idea to pre-check the system to make sure it's operating properly before you launch your boat.

➡ If your boat should happen to stall, water currents will slowly carry it to shore. The bad news is the boat could be carried to the opposite shore. When surveying areas to run your model, keep variables in mind such as wind direction, size of the lake, etc. It is not advisable to run R/C boats on any freefl owing bodies of water such as creeks or rivers.

FEATURES AND SPECIFICATIONS:

REVOLT FEATURES:

Hand laid fiberglass hull and canopy Roomy interior Tactic 2.4GHz radio system (Performance 2.4GHz Version Only) AquaCraft 1800 KV 6 pole motor

AquaCraft 60amp Motor Controller Aluminum water jackets on both the motor and controller New high-performance 25-35 GrimRacer boat hardware

Battery tray accepts many battery mounting confi gurations Hook and loop battery mounting Other outstanding features include:

High gloss painted fi nish

Pre-applied graphics

Brass stuffi ng tube

Low friction cable guide

.150” fl ex drive cable

Industry standard 3/16” (.187”) prop shaft GrimRacer 42x55 Metal Propeller

BASIC HULL SPECIFICATIONS:

Hull Length: 30” (762mm)

Overall Length: 33.5” (850.9mm)

Width: 9.125” (235mm)

MOTOR SPECIFICATIONS:

MOTOR CONTROLLER SPECIFICATIONS:

Length: 100mm

Width: 38mm

Height: 17mm

Weight: 3.8oz (109grams)

Wire Gauge: 14g

Battery Connectors: Male Deans® Ultra Plugs® (2)

Motor Connectors: 4mm gold plated bullet connectors (3)

Input Voltage: 12-14 NiMH

4 cells LiPo

8-20V input w/o BEC)

Output Current: 60A continuous maximum

72A surge maximum

Max Output Power: 720 watts

On-resistance: 0.003 ohms

Operating frequency: 8kHz

BEC: 5.2V/2A

Stutter Bump Voltage: 12V

Low Voltage Cutoff: 11.6V

Thermal Cutoff: 110C Timing Angle: 10°

PLEASE READ:

Notes about using LiPo batteries in your boat: The Revolt uses the AquaCraft 60amp motor controller. This controller has a built-in stutter bump system that cycles the power to the motor when the battery voltage reaches 12V. This is designed to warn you of impending low battery voltage and subsequent shut down. It also has a 10.8V battery cut off safety system that shuts the power down to the motor to avoid damaging the batteries.

Having said this, as a rule of thumb we have found it best in very high current draw application like an RC boat, to not to use more than 70% of the rated capacity of the battery pack, per run. We have also found that when in doubt and using the recommended propellers you can expect to use about 1000mAh (give or take) per minute of operation. Using this you can better judge your runs knowing you're taking the very best care of your battery pack investment.

GrimRacer says: It's best to test this by making a timed 2 min run. Then charge the batteries back up and note the amount of mAh the pack allowed back in. Do this each and every time you make a prop change or any other significant change to your setup. Then adjust your driving time so you don't go over the 70% usage mark.

Also keep in mind that RC car packs (hard case) could be used. But if you get them wet, they can store water, causing the internal metal parts of the pack to corrode, and in turn causing short pack life. We highly recommend using dedicated marine LiPo packs like those in the GrimRacer Line.

START UP AND OPERATION:

IMPORTANT:

Your Revolt is a true racing boat. In our quest to provide you with the very best performance, we feel it is important to remind you that the water pickup that cools the electronics is located on the left side of the rudder blade. The reason it is mounted on the left is, in RC boat racing we take advantage of prop torque and turn left on the racing circuit ("typically this is an oval course"). CAUTION: Constantly turning right can cause a loss of cooling to the electronics and should be avoided.

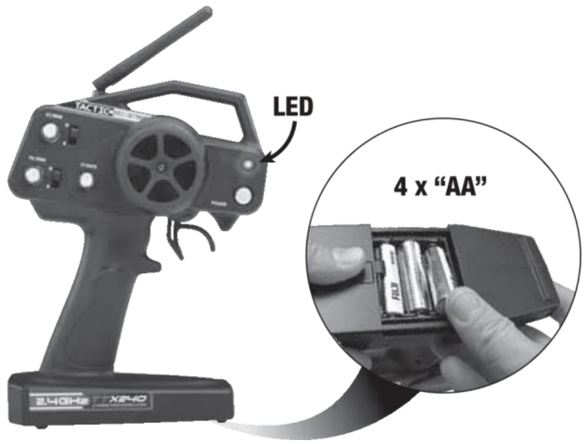


Figure A- 1 Boat controller

If you have the Performance 2.4GHz version, install 4 "AA" batteries into the transmitter using the installation pattern molded into the bottom of the battery tray. Turn on the transmitter, making sure it's working by viewing the LED By separating these errors, one can evaluate the total error independent of the gain setting used. In a given gain configuration both errors can be combined to give a total error referred to the input (R.T.I.) or output (R.T.O by the followingAs an illustration, a typical AD624 might have a +250 µV output offset and a –50 µV input offset. In a unity gain configuration, the total output offset would be 200 µV or the sum of the two. At a gain of 100, the outpu As an illustration, a typical AD624 might have a +250 µV output offset and a –50 µV input offset. In a unity gain configuration, the total output offset would be 200 µV or the sum of the two. At a gain of 100, the output As an illustration, a typical AD624 might have a +250 µV output offset and a –50 µV input offset. In a unity gain configuration, the total output offset would be 200 µV or the sum of the as an illustration, a typical AD624 might have a +250 µV output offset and a –50 µV input offset. In a unity gain configuration, the total output offset would be 200 µV or the sum of the two. At a gain of 100, the output

Remove the canopy and install the batteries, making sure they are well strapped in and seated two. At a gain of 100, the output

As an illustration, a typical AD624 might have a +250 µV output offset and a –50 µV input offset. In a unity gain configuration, the total output offset would be 200 µV or the sum of the two. At a gain of 100, the output

Remove the canopy and install the batteries, making sure they are well strapped in and seated. As an illustration, a typical AD624 might have a +250 µV output offset and a –50 µV input offset. In a unity gain configuration, the total output offset would be 200 µV or the sum of the two. At a gain of 100, the output

Remove the canopy and install the batteries, making sure they are well strapped in and seated. Remove the canopy and install the batteries, making sure they are well strapped in and seated.

Remove the canopy and install the batteries, making sure they are well strapped in and seated

Remove the canopy and install the batteries, making sure they are well strapped in and seated. As an illustration, a typical AD624 might have a +250 µV output offset and a –50 µV input offset. In a unity gain configuration, the total output offset would be 200 µV or the sum of the two. At a gain of 100, the output

Remove the canopy and install the batteries, making sure they are well strapped in and seated.

No signal between the transmitter and the boat (Performance 2.4GHz version):

Check to make sure the transmitter is bound to the receiver. To bind: With the transmitter turned on and the batteries plugged into the boat, press and hold the bind button on the top of the receiver (use a toothpick or other small pointed object) for approximately 4 seconds or until the system binds. You will know it is bound when the small LED hidden behind the face of the receiver stops flashing and stays lit.

Boat runs backwards:

Switch any two of the three motor wires. Motor Controller will not arm:

Move the throttle trim knob slowly clockwise (or a lesser percentage) to adjust the center point of the throttle system.

First make sure the cable coupler is tight. If it’s OK, try being more aggressive with the throttle during the launch or toss the boat forward with more force, applying power as the boat touches the water. Boat slows down or shuts off in the middle of a run:

Check for weeds on the prop or any obstruction blocking the water cooling pick up.

After a run the motor, batteries and or motor controller are very hot: Check to make sure the water pickup is not plugged. Check to see that the prop is not bent or that you have changed to a propeller that is too large for the power system.

After each five or so runs and or after a day of running it’s a good idea to relubricate the drive cable. Here are the tools and supplies you need to complete the task.

10mm open end wrench

12mm open end wrench

AquaCraft GrimRacer Speed Grease Paper towel

6. Loosen the cable coupler using the 10 and 12mm wrenches. 7. Firmly pull the prop and drive shaft out of the back of the boat. Now is a good time to inspect the bushing for excess wear.

Wipe away any old grease and water. Apply new speed grease to the shaft and slide it back into the strut, moving it in and out as you do so to help spread the grease along the length of the cable.

Before tightening the cable coupler make sure to leave a 4 or 5mm distance between the back of the strut and the front of the drive dog. This will keep the drive system from binding or breaking as the cable operates. Tighten the cable coupler, reversing the direction of the open end wrenches. DO NOT OVERTIGHTEN.

NOTE: The drive cable is supported by the brass stuffing tube which has a low friction liner. The prop shaft (or “stub shaft”) is hard- soldered to the flexible drive cable and spins in a brass bushing located in the back of the stuffing tube. The bushing and liner should be replaced when they start to show wear. AQUB7884 Prop Shaft Bushing AQUB7869 .150” Cable Liner 10” (cut to length as needed)

At the end of the day make sure to leave the cowl off and the drain plug out overnight. This will allow any moisture that collected in the boat to safely evaporate.

TUNING TIPS AND PROP INFO: “The Business End of the Boat”

Strut: Tilting the strut down or lowering it tightens the ride of the boat. A “tighter ride” will help stabilize the boat but at the risk of more power consumption as well as a loss of speed. It’s also important to note that this “tight ride” could cause the ESC and or motor to overheat. Tilting the strut up or raising it loosens the boat ride. This looser ride allows the boat to go faster but at the risk of a blow off (the boat lifting off the water). It’s best to make small strut adjustments and only make one small change at a time.

Rudder: The rudder can be tuned in a variety of ways. The most important aspect is how sharp it is or you make it. Using a fl at fi le, sharpen the leading edge of the rudder finishing with 400 grit, then 600 grit wet/dry sandpaper. You can also gain some performance if you remove the lift the rudder makes off the bottom of the blade. You can either round or sharpen the bottom of the blade as either method works. Another important aspect is the angle front to back of the rudder blade. Tilting the rudder back and forth also changes the way the boat operates. Tilting the rudder under the boat tightens the ride while tilting it back loosens it.

CG: Adjusting the CG or center of gravity of the boat has a lot to do with how tight the boat rides as well as the how the boat “flies” as it enters and exits the water. Moving the battery packs forward or rearward is the best way to adjust the CG.

Scuffing: Scuffing is a tuning trick boat racer use to increase the speed of their boat. Scuffing involves dulling the area/s of the boat that touch the water as the boat is running. We like to use a red scratch pad like the ones you find in the paint section of your local home supply store. Scuff the bottom of the boat to the point the shine is removed from the paint. While this tuning trick is mostly geared towards the hard core boat racer, sport runners can benefit from this as well. GrimRacer says if you scuff the boat and don’t like the way it looks, don’t come running back to me for a new hull. I’m just trying to help you win some races so don’t shoot the messenger! Now let’s go racing!

Props: About the best we can do is help guide you to a better performing prop. Ultimately how you drive and tune your boat will determine the best prop for your racing program. Having said that, we have found the GrimRacer 42x55 (AQUB9725) is about the best overall prop for your Revolt. It is also advisable that you balance your propeller when it is new and check it for balance periodically. If you want to learn more about tuning props check out some of the How to Balance Your Propeller link at aquacraftmodels.com.

RACING:

Your Revolt was designed to fi t into boat IMPBA and NAMBA P class racing. What you will find is power systems designed for this boat and others like it making their own class called P-Spec. This boat fits into the P-Spec Mono racing class. Check the websites listed below for information and places to race your Revolt.

NATIONAL ORGANZATIONS AND ONLINE HELP:

www.impba.net www.namba.com www.ampba.asn.au www.aquacraftmodels.com www.inltlwaters.com www.rcgroups.com www.rcuniverse.com

ORDERING REPLACMENT PARTS:

Appendix B

The Leader in Force Measurement

Interface
ADVANCED FORCE MEASUREMENT

Model SSMH Sealed S-Type Load Cell for Hazardous Environments (U.S. & Metric)

- Proprietary Interface temperature compensated strain gages
- Environmentally sealed IP65
- High temperature rated 290°F (143°C)
- Tension or compression
- Certified for explosion protection by intrinsic safety for dust and gas per ATEX designations

Ex II 2 D Ex ib IIIC T160°C (-40 < Ta < 143°C)

Ex II 2 G Ex ib IIC T4 (-40 < Ta < 112°C)

STANDARD CONFIGURATION

10 ft (3 m) Integral Cable

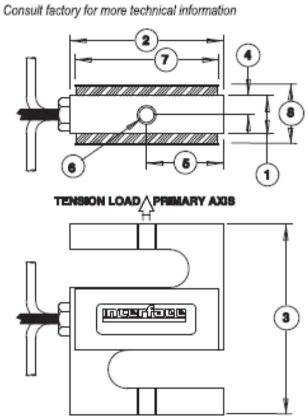
OPTIONS

Standardized Output
Special Cable Length - up to 300 ft (100 m)

ACCESSORIES

Load Button
Instrumentation
Mounting Hardware

Consult factory for more technical information



CE

Intrinsic Safety Entity Parameters	
Ui	20 V
Ii	460 mA
Pi	1.3 W
Ci	15 nF
Li	51 µH

SPECIFICATIONS

ACCURACY – (MAX ERROR)	
Nonlinearity–% FS	±0.05
Hysteresis–% FS	±0.03
Nonrepeatability–% RO	±0.02
Creep in 20 min–%	±0.025
TEMPERATURE	
Compensated Range–°F (°C)	0 to 150 (-15 to 65)
Operating Range–°F (°C)	-40 to 290 (-40 to 143)
Effect on Output–%/°F – MAX (°C)	±0.0008 (±0.0015)
Effect on Zero– % RO/°F – MAX (°C)	±0.0015 (±0.0027)
ELECTRICAL	
Rated Output–mV/V (Nominal)	3
Zero Balance–%RO	±1
Bridge Resistance–Ohm (Nominal)	350
Excitation Voltage–MAX	15 VDC
Insulation Resistance–Megohm	>5000
MECHANICAL	
Calibration	Tension
Safe Overload–% CAP	150
Cable Length–ft (m)	10 (3)
Natural Frequency/Deflection:	

lbf	N	Deflection (in)	Nat. Freq. (Hertz)
50	200	.003	1500
100	500	.004	1850
150	700	.004	2000
250	1000	.006	2350
500	2000N	.005	2150
750	3000N	.005	2350
1000	5000N	.005	3350
2000	10kN	.005	2400
3000	15kN	.005	3000
5000	20kN	.005	2520

DIMENSIONS

See Drawing	CAPACITY (lbf)							
	lbf	N	lbf	N	lbf	kN	lbf	kN
	50	200	100 150 250	500 700 1000	500 750 1K 2K 3K	2, 3 5 10 15	5K	20
	inch	mm	inch	mm	inch	mm	inch	mm
(1)	0.50	12.7	0.50	12.7	1.00	25.4	1.50	38.1
(2)	2.00	50.8	2.00	50.8	2.00	50.8	2.50	63.5
(3)	2.50	63.5	2.50	63.5	3.00	76.2	3.50	88.9
(4)	0.25	6.40	0.25	6.40	0.50	12.7	0.75	19.1
(5)	1.00	25.4	1.00	25.4	1.00	25.4	1.25	31.8
(6)	1/4-28 UNF -2B	M6 x 1-6H	1/4-28 UNF -2B	M6 x 1-6H	1/2-20 UNF -2B	M12 x 1.75-6H	5/8-18 UNF -2B	M16 x 2-6H
(7)	1.88	47.8	1.88	47.8	1.88	47.8	2.38	60.5
(8)	0.82	20.8	0.72	18.3	1.22	31.0	1.75	44.5

89

Figure B- 1 Load Cell

Appendix C

Connecting the NI 9205

The NI 9205 is a 32-channel single-ended/16-channel differential analog input module.

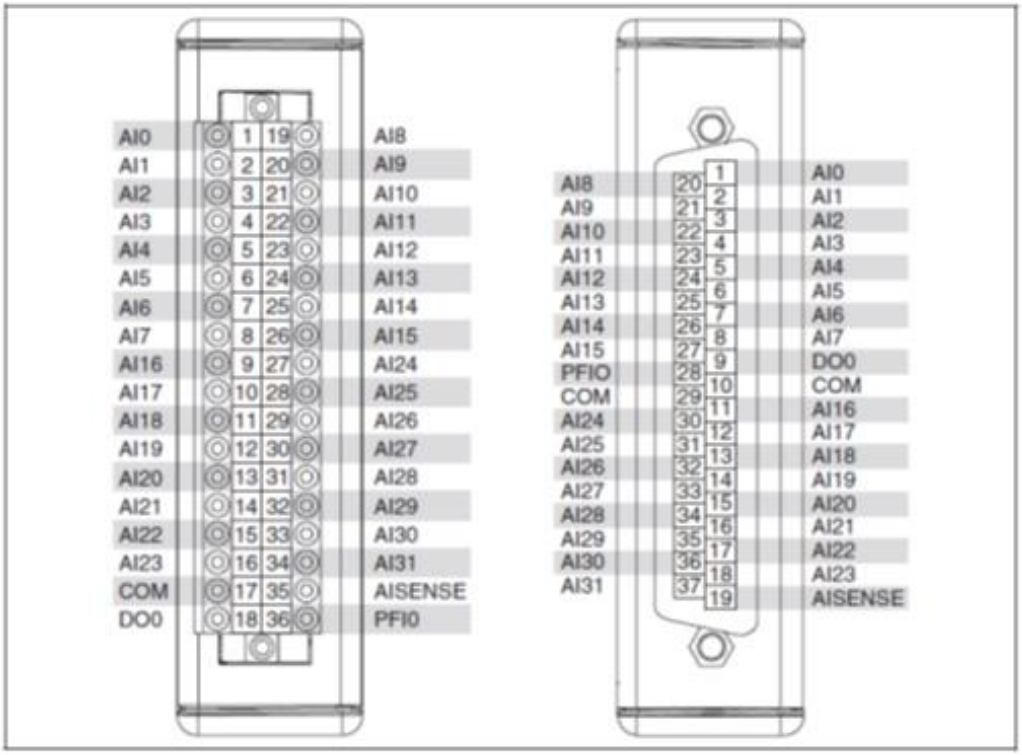


Figure C- 1 National Instrument Data Acquisition ports

Appendix D

Precision Instrumentation Amplifier

AD624 FEATURES

Low Noise: 0.2 V p-p 0.1 Hz to 10 Hz

Low Gain TC: 5 ppm max (G = 1)

Low Nonlinearity: 0.001% max (G = 1 to 200)

High CMRR: 130 dB min (G = 500 to 1000)

Low Input Offset Voltage: 25 V, max

Low Input Offset Voltage Drift: 0.25 V/C max

Gain Bandwidth Product: 25 MHz

Pin Programmable Gains of 1, 100, 200, 500, 1000

No External Components Required

Internally Compensated

PRODUCT DESCRIPTION

The AD624 is a high precision, low noise, instrumentation amplifier designed primarily for use with low level transducers, including load cells, strain gauges and pressure transducers. An outstanding combination of low noise, high gain accuracy, low gain temperature coefficient and high linearity make the AD624 ideal for use in high resolution data acquisition systems.

The AD624C has an input offset voltage drift of less than

0.25 µV/°C, output offset voltage drift of less than 10 µV/°C, CMRR above 80 dB at unity gain (130 dB at G = 500) and a maximum nonlinearity of 0.001% at G = 1. In addition to these outstanding dc specifications, the AD624 exhibits superior ac performance as well. A 25 MHz gain bandwidth product, 5 V/µs slew rate and 15 µs settling time permit the use of the AD624 in high speed data acquisition applications.

The AD624 does not need any external components for pretrimmed gains of 1, 100, 200, 500 and 1000. Additional gains such as 250 and 333 can be programmed within one percent accuracy with external jumpers. A single external resistor can also be used to set the 624's gain to any value in the range of 1 to 10,000.

FUNCTIONAL BLOCK DIAGRAM

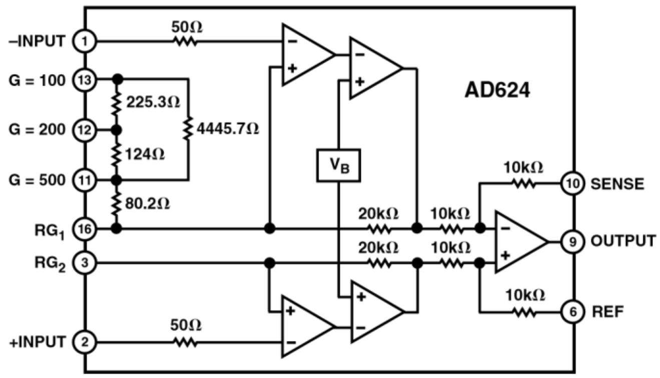


Figure D- 1 Amplifier Block Diagram

The AD624 offers outstanding noise performance. Input noise is typically less than 4 n V/√Hz at 1 kHz.

The AD624 is a functionally complete instrumentation amplifier. Pin programmable gains of 1, 100, 200, 500 and 1000 are provided on the chip. Other gains are achieved through the use of a single external resistor.

The offset voltage, offset voltage drift, gain accuracy and gain temperature coefficients are guaranteed for all pretrimmed gains.

The AD624 provides totally independent input and outputoffset nulling terminals for high precision applications. This minimizes the effect of offset voltage in gain ranging applications.

A sense terminal is provided to enable the user to minimizethe errors induced through long leads. A reference terminal is also provided to permit level shifting at the output.

Supply Voltage . . . . ±18 V

Internal Power Dissipation . . . . 420 mW

Input Voltage . . . . ±VS

INPUT Differential Input Voltage . . . . ±VS

+INPUT Output Short Circuit Duration . . . . Indefinite RG2

Storage Temperature Range . . . . –65°C to +150°C INPUT

NULLSHORT TOOperating Temperature Range INPUT NULL RG2 FOR

DESIRED AD624A/B/C . . . . –25°C to +85°C

GAINAD624S . . . . –55°C to +125°C –VS

Lead Temperature (Soldering, 60 secs) . . . . +300°C+VS

Stresses above those listed under Absolute Maximum Ratings may cause permanent damage to the device. This is a stress rating only; GAINS OF 1000 SHORT RG1 TO PIN 12 device at these or any other conditions above those indicated in the operational AND PINS 11 AND 13 TO RG2 sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.Supply Voltage . . . . ±18 V

Internal Power Dissipation . . . . 420 mW

Input Voltage . . . . ±VS –INPUT

Differential Input Voltage . . . . ±VS +INPUT Output

Short Circuit Duration . . . . Indefinite RG2

Storage Temperature Range . . . . –65°C to +150°C INPUT

Operating Temperature Range INPUT NULL RG2 FOR

DESIRED

AD624A/B/C . . . . –25°C to +85°C REF GAIN

AD624S . . . . –55°C to +125°C –VS

Lead Temperature (Soldering, 60 secs) . . . . +300°C +VS

The AD624 includes high accuracy pretrimmed internal gain resistors. These allow for single connection programming of gains of 1, 100, 200 and 500. Additionally, a variety of gains including a pretrimmed gain of 1000 can be achieved through series and parallel combinations of the internal resistors. Table I shows the available gains and the appropriate pin connections and gain temperature coefficients.

The gain values achieved via the combination of internal resistors are extremely useful. The temperature coefficient of the gain is dependent primarily on the mismatch of the temperature coefficients of the various internal resistors. Tracking of these resistors is extremely tight resulting in the low gain TCs shown in Table I.

If the desired value of gain is not attainable using the internal resistors, a single external resistor can be used to achieve any gain between 1 and 10,000. This resistor connected between

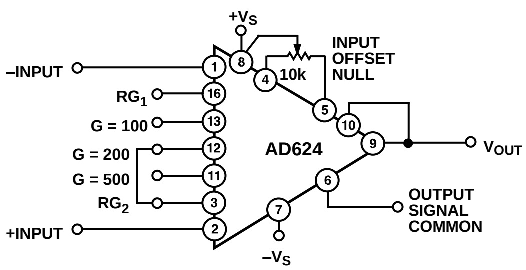


Figure D- 2 Amplifier Connections For G =200

Pins 3 and 16 programs the gain according to the formula 40k RG

(see Figure 29). For best results RG should be a precision resistor with a low temperature coefficient. An external RG affects both gain accuracy and gain drift due to the mismatch between it and the internal thin-film resistors R56 and R57. Gain accuracy is determined by the tolerance of the external RG and the absolute accuracy of the internal resistors (±20%). Gain drift is determined by the mismatch of the temperature coefficient of RG and the temperature coefficient of the internal resistors (–15 ppm/°C typ), and the temperature coefficient of the internal interconnections.

Figure 29. Operating Connections for G = 20

The AD624 may also be configured to provide gain in the output stage. Figure 30 shows an H pad attenuator connected to the reference and sense lines of the AD624. The values of R1, R2 and R3 should be selected to be as low as possible to minimize the gain variation and reduction of CMRR. Varying R2 will precisely set the gain.

Appendix E

```
s=xlsread('1700mghofilterspringxlsx.xlsx','Sheet1','A8001:C9001');

[n,m] = size(s); x=s(:,1); y=s(:,3)/1000; force  =  s(:,2)*4.44882; yu = max(y); yl =
min(y);

yr = (yu-yl);                    % Range of 'y' yz = y-yu+(yr/2); p=97; %%

threshold = prctile(y,p); % it is matlab method to find the max available thrsold for upper.

threshold2 = prctile(-y,p);% it is matlab method to find the max available thrsold for
lower.

%method to mesure the uper and lower limits of threshold using .4 factor.

%%

thresholdupper = (mean(y)+.4*((max(y)-min(y)))); thresholdown = (mean(y)-
.4*((max(y)-min(y)))) ;

%%

% first for loop to turn all values upper thatn uper limit to be uper limit value

% same for lower than lower   % set the values in between to be zero yy=y; for
i=1:length(y)-1     if y(i)>=thresholdupper;        yy(i)=thresholdupper;


   elseif y(i)<=thresholdown;         yy(i)=thresholdown ;


   elseif thresholdupper>y(i)>thresholdown;        yy(i)=0; end end

% Fixing Noize if there is disturbance  for i=1:length(yy)-1      if yy(i+1)~=0        if
yy(i+1)<thresholdupper   && yy(i)==thresholdupper            yy(i+1)=thresholdupper;
elseif yy(i+1)>thresholdown && yy(i)==thresholdown            yy(i+1)=thresholdown;
elseif yy(i+1)~=thresholdupper  && yy(i+1)~=thresholdown && yy(i)==0
yy(i+1)=0;         end         end  end

%calculate the time Period

t=1; LL=1;

for i=1:length(yy)-1

   if yy(i+1)==thresholdupper && yy(i)~=thresholdupper

      ss(t)=x(i+1);
```

```
t=t+1;

elseif yy(i)==thresholdupper && yy(i+1)~=thresholdupper        nn(LL)=x(i+1);
LL=LL+1;    end   end

for i=1:length(ss)-1     p(i)=ss(i+1)-ss(i); end

ptimeperiod=(max(p)+min(p))/2; %ptimeperiod=mean(p); amp=(threshold+threshold2)/2

%ampo=(thresholdupper-thresholdown)/2

%zx = x(yz(:) .* circshift(yz(:),[1 0]) <= 0);     % Find zero-crossings per = ptimeperiod;
% Estimate period ym=((max(y)+min(y))/2); %ym=(threshold+threshold2)/2;

%ym = mean(y);                         % Estimate offset                         fit = @(b,x)
b(1).*(sin(2*pi*x./b(2) + 2*pi/b(3))) + b(4);    % Function to fit fcn = @(b) sum((fit(b,x)
- y).^2);                          % LeastSquares cost function

s = fminsearch(fcn, [amp;  per;  -1;  ym])                   % Minimise Least-Squares

xp = linspace(min(x),max(x)); figure(1)

plot(x,y,'b',  x,fit(s,x), 'r') xlabel('time')  ylabel('displacement real-analytic')
yanalytic=fit(s,x);

%% amplitude=s(1); timeperiod=s(2); phase=s(3); ofset=s(4); freqency=1/timeperiod;
omega=2*pi*freqency

%%

%subsitute in new sineqaution  ampp=amplitude rr=(ofset-ym)/2; syms tt

soo =  amplitude.*(sin(2*pi*tt./timeperiod + 2*pi/phase)) + (ofset); tt=x;

coopp= subs(soo,tt);

analyticdisplacement2=double(coopp); figure(5)

plot (x, analyticdisplacement2,x, y) xlabel('time') ylabel('displacement real-analytic')
%determine the velocity dx/dt

ve=diff(soo); Vv=subs(ve,tt); vell=double(Vv); figure(2) plot (vell,force)
xlabel('velocity') ylabel('real force') %%

%find points when ve=0 vz=[];

  for i = 1:length(vell)-1     if vell(i)*vell(i+1)<=0       temp=force(i)+(force(i+1)-

force(i))*abs(vell(i))/(abs(vell(i))+abs(vell(i+1)));       vz=[vz temp];     end    end     %%

   %find nearest points to max and nearest to min   a=mean(vz); j=1; d=1; for
i=1:length(vz)     if vz(i)>a        fmaxx(j)=vz(i);        j=j+1;     else        fminn(d)=vz(i);
d=d+1;     end end
```

```
%%
%find the ofset
%find the ofset
 Max =mean(fmaxx);
Min=mean(fminn);
%obaaa=((max(fmaxx)-min(fminn))/2)-((Max-Min)/2);
obaa=((max(fmaxx)+min(fminn))/2)
%if abs(Max)>abs(Min)
 % obaa=(Max-Min)/2 %else  %   obaa=-(Max-Min)/2 %end
%obaa=(Max+Min)/2
%obaa=mean(vz)-(Max+Min)/2
%%
%subtract ofset forcefrom the input force ftotal =force-obaa; figure(3) plot(vell,ftotal);
%find the positive values of force after subtract the ofset  fp=subplus(ftotal); %% ...........
%max value of positive force when v=0 whenafter subtract the ofset force vz2=[];
for i = 1:length(vell)-1     if vell(i)*vell(i+1)<=0        tempp=fp(i)+(fp(i+1)-
fp(i))*abs(vell(i))/(abs(vell(i))+abs(vell(i+1)));        vz2=[vz2 tempp];     end end %%
fmax=max(vz2)
%determinet the spring stifness k=fmax/amplitude fspring=k*analyticdisplacement2;
fspring1=fspring(1:end-1); %subtract from force ftotal2=ftotal-fspring; fsmooth=
smooth(ftotal2);% smooth force figure(4) plot(vell,fsmooth) xlabel('velocity m/s')
ylabel('force N')  vz3=[]; for i = 1:length(vell)-1     if vell(i)*vell(i+1)<=0
tempp=ftotal2(i)+(ftotal2(i+1)ftotal2(i))*abs(vell(i))/(abs(vell(i))+abs(vell(i+1)));
vz3=[vz3 tempp];     end end oppa2=max(vz3) ftotal3=ftotal2-oppa2; ffsmooth=
smooth(ftotal3); figure(8) plot(vell,ffsmooth) xlabel('velocity m/s') ylabel('force N')
s=xlsread('1700mghofilterspringxlsx.xlsx','Sheet1','A8001:C10001');
[n,m] = size(s); x=s(:,1); y=s(:,3)/1000; force  =  s(:,2)*4.44882; yu = max(y); yl =
min(y);
yr = (yu-yl);                         % Range of 'y' yz = y-yu+(yr/2); p=97; %%
threshold = prctile(y,p); % it is matlab method to find the max available thrsold for upper.
threshold2 = prctile(-y,p);% it is matlab method to find the max available thrsold for
lower.
```

```
%method to mesure the uper and lower limits of threshold using .4 factor.

%%

thresholdupper = (mean(y)+.4*((max(y)-min(y)))); thresholdown = (mean(y)-
.4*((max(y)-min(y)))) ;

%%

% first for loop to turn all values upper thatn uper limit to be uper limit value

% same for lower than lower   % set the values in between to be zero yy=y; for
i=1:length(y)-1     if y(i)>=thresholdupper;        yy(i)=thresholdupper;

    elseif y(i)<=thresholdown;         yy(i)=thresholdown ;


    elseif thresholdupper>y(i)>thresholdown;        yy(i)=0; end end

% Fixing Noize if there is disturbance  for i=1:length(yy)-1      if yy(i+1)~=0        if
yy(i+1)<thresholdupper   && yy(i)==thresholdupper            yy(i+1)=thresholdupper;
elseif yy(i+1)>thresholdown && yy(i)==thresholdown            yy(i+1)=thresholdown;
elseif yy(i+1)~=thresholdupper  && yy(i+1)~=thresholdown && yy(i)==0
yy(i+1)=0;         end         end  end

%calculate the time Period

t=1; LL=1;

for i=1:length(yy)-1     if yy(i+1)==thresholdupper && yy(i)~=thresholdupper
ss(t)=x(i+1);       t=t+1;

        elseif yy(i)==thresholdupper && yy(i+1)~=thresholdupper        nn(LL)=x(i+1);
LL=LL+1;     end   end

for i=1:length(ss)-1

    p(i)=ss(i+1)-ss(i); end

%ptimeperiod=(max(p)+min(p))/2; ptimeperiod=mean(p); amp=(threshold+threshold2)/2

%amp=.5

%ampo=(thresholdupper-thresholdown)/2

%zx = x(yz(:) .* circshift(yz(:),[1 0]) <= 0);     % Find zero-crossings per = ptimeperiod;
% Estimate period ym=((max(y)+min(y))/2); %ym=(threshold+threshold2)/2;

%ym = mean(y);                    % Estimate offset

%ym = ((max(y)-min(y))/2);
```

fit = @(b,x) b(1).*cos((2*pi*x./b(2) + 2*pi/b(3)))+sqrt(b(4).^2b(1).^2*(sin(2*pi*x./b(2) + 2*pi/b(3)).^2))+ b(5);

%fit = @(b,x) b(1).*(sin(2*pi*x./b(2) + 2*pi/b(3))) + b(4);   % Function to fit fcn = @(b) sum((fit(b,x) - y).^2);   % LeastSquares cost function s = fminsearch(fcn, [amp; per; -.6;   0.01 ;ym])   % Minimise Least-Squares xp = linspace(min(x),max(x)); figure(1)

plot(x,y,'b', x,fit(s,x), 'r') xlabel('time') ylabel('displacement real-analytic') yanalytic=fit(s,x);

%% amplitude=s(1) timeperiod=s(2) phase=s(3); ofset=s(5) l=s(4) freqency=1/timeperiod; omega=2*pi*freqency

%%

%subsitute in new sineqaution ampp=amplitude;

ofdif=(max(y)-max(yanalytic)); ofdifmin=(min(y)-min(yanalytic)); tot=(ofdif+ofdifmin)/2 syms tt

soo = amplitude.*cos((2*pi*tt./timeperiod + 2*pi/phase))+sqrt(l.^2amplitude.^2*(sin(2*pi*tt./timeperiod + 2*pi/phase).^2))+(ofset); tt=x; coopp= subs(soo,tt); analyticdisplacement2=double(coopp); figure(5)

plot (x, analyticdisplacement2,x, y) xlabel('time') ylabel('displacement real-analytic') %determine the velocity dx/dt

ve=diff(soo); Vv=subs(ve,tt); vell=double(Vv); figure(2) plot (vell,force) xlabel('velocity') ylabel('real force')

%%

%find points when ve=0 vz=[];

for i = 1:length(vell)-1   if vell(i)*vell(i+1)<=0   temp=force(i)+(force(i+1)-

force(i))*abs(vell(i))/(abs(vell(i))+abs(vell(i+1)));   vz=[vz temp];   end   end   %%

%find nearest points to max and nearest to min   a=mean(vz); j=1; d=1; for i=1:length(vz)   if vz(i)>a   fmaxx(j)=vz(i);   j=j+1;   else   fminn(d)=vz(i); d=d+1;   end end

%%

%find the ofset

%find the ofset

Max =mean(fmaxx);

Min=mean(fminn);

```
%obaaa=((max(fmaxx)-min(fminn))/2)-((Max-Min)/2);
obaa=((max(fmaxx)+min(fminn))/2)

%if abs(Max)>abs(Min)

 % obaa=(Max-Min)/2 %else  %   obaa=-(Max-Min)/2 %end

%obaa=(Max+Min)/2

%obaa=mean(vz)-(Max+Min)/2

%%

%subtract ofset forcefrom the input force ftotal =force-obaa; figure(3)

plot(vell,ftotal);

%find the positive values of force after subtract the ofset  fp=subplus(ftotal); %% ..........

%max value of positive force when v=0 whenafter subtract the ofset force vz2=[];

for i = 1:length(vell)-1     if vell(i)*vell(i+1)<=0        tempp=fp(i)+(fp(i+1)-

fp(i))*abs(vell(i))/(abs(vell(i))+abs(vell(i+1)));

vz2=[vz2 tempp];     end end %%

fmax=max(vz2)

%determinet the spring stifness k=fmax/amplitude

fspring=k*analyticdisplacement2; fspring1=fspring(1:end-1); %subtract from force
ftotal2=ftotal-fspring; fsmooth= smooth(ftotal2);% smooth force figure(4)
plot(vell,fsmooth) xlabel('velocity m/s')  ylabel('force N')  vz3=[];

for i = 1:length(vell)-1     if vell(i)*vell(i+1)<=0        tempp=ftotal2(i)+(ftotal2(i+1)-

ftotal2(i))*abs(vell(i))/(abs(vell(i))+abs(vell(i+1)));        vz3=[vz3 tempp];     end end
oppa2=max(vz3) ftotal3=ftotal2-oppa2; ffsmooth= smooth(ftotal3); figure(8)
plot(vell,ffsmooth) xlabel('velocity m/s') ylabel('force N')
```

Appendix F

FEATURES

Triaxial Accelerometers

Piezoresistive (±100 / 500g)

Piezoelectric (±25 / 100 / 500 / 2,000g)

DC Response MEMS (16 / 200g)

Configurable Sampling Rate up to 20 kHz

Up To 4 Billion Data Points Onboard Memory

Temperature & Pressure Sensors

Time Stamped Data with Local Calendar Time

Manual & Automatic Start/Trigger Modes

Rechargeable Battery Life (>12hrs)

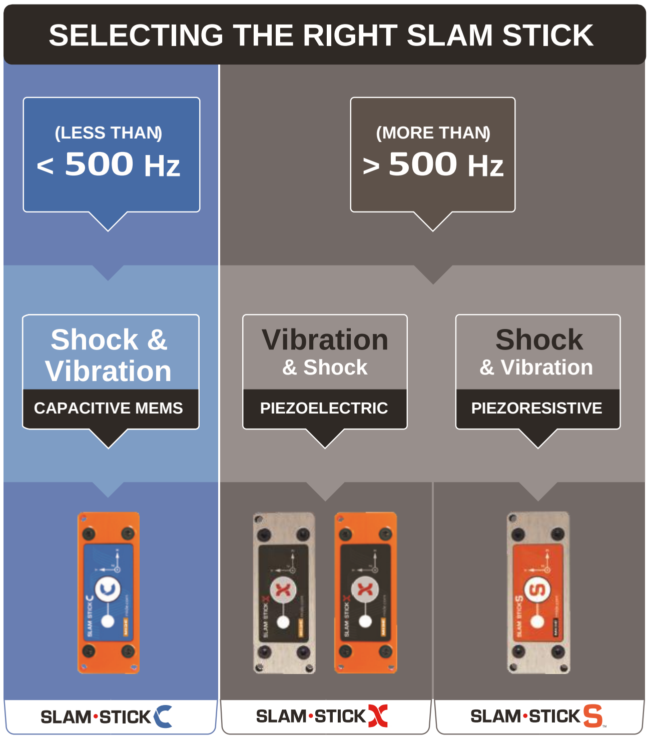
Lightweight

Micro-USB Interface for Set-Up & Data Download

Free Analysis Software (Slam Stick Lab)

EMI Qualified (MIL-STD-461F)

5th Order Hardware Low-Pass Filter



Shock & Vibration Data Loggers

Figure F- 1 different slam sticks

The Slam Stick data loggers are capable of measuring acceleration in all three axes while also measuring temperature and pressure. The recorders are available with two enclosure options (aluminum or polycarbonate), different measurement ranges (±16g to ±2,000g), and an industry leading high sample rate (up to 20 kHz on the piezoelectric and piezoresistive accelerometers and up to 3.2 kHz on the DC response MEMS accelerometer).

Their lightweight design and large surface area minimize mass loading and enable two mounting options: adhesive mounting using the industrial strength double sided tape included with the product; or hard mounting, for an even higher frequency response. Its rugged enclosure and wide temperature operating range (-40°C to 80°C) enable the Slam Stick to perform in many harsh environments.

A micro-USB receptacle allows for quick and easy connection to a computer where data can be analyzed with Midé's provided software package - Slam Stick Lab. The software also enables configuration of the device to meet a variety of customer needs. Triggers include time delays, calendar date/time wake up and acceleration, temperature and/or pressure triggers.

Sensors Triaxial Accelerometers

Piezoelectric (±25 / 100 / 500 / 2,000g)

Optional DC Response MEMS (±16 / 200g)

Pressure

Temperature

Applications

Qualification tesing

High frequency vibration

Dimensions

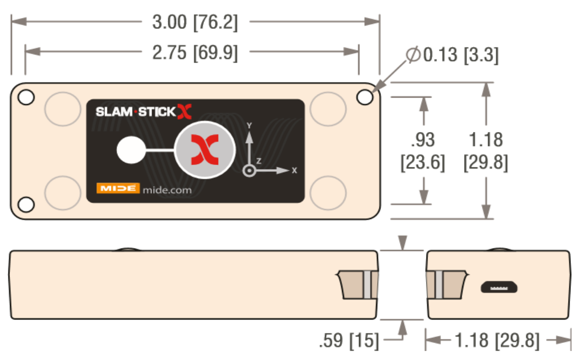


Figure F- 2 Slam Stick Dimensions

ACCELEROMETER OVERVIEW

The triaxial piezoelectric accelerometer, when compared to the DC MEMS accelerometer, offers a higher data quality. Piezoelectric accelerometers are the most popular because of their versatility but they have two disadvantages: an AC coupling, and their charge amplifier can become saturated during high frequency and/or amplitude shock events.

BATTERY & STORAGE CAPACITY

Table F- 1 Slam stick Battery life

Per Channel Sampling Frequency (Hz)	Time available for 2 GB (hours)	Battery Life (hours)
100	1000	14.0
1,000	100	13.5
5,000	20	11.0
20,000	5	3.5

ACCELEROMETER OVERVIEW

The piezoresistive accelerometer offers similar advantages as the piezoelectric in terms of data quality. But they have the added benefit of being capable of measuring static accelerations and low frequency vibrations. They also have internal gas damping to widen the dynamic frequency range of the accelerometer. These accelerometers are increasingly becoming more popular for shock and vibration testing applications.

EXTENDING BATTERY & STORAGE

The Slam Stick can record data even while plugged into power. External power supplies, such as standard portable phone chargers work well. When plugged into an external power source, the Slam Stick will record until it runs out of storage. An upgrade to a 8GB storage card is available. Note that a single recording file size is limited to 4 GB.

Utilize triggering configurations to further increase battery and storage capacity.

The rechargable battery has a lifetime of 3 years and needs to be charged at least twice a year. For more info refer to component datasheet section in user manual (pdf).

SOFTWARE OVERVIEW & FEATURES

Configure Slam Stick C, X & S data loggers
Import and display data
Vibration analysis - FFT, PSD and spectrogram
Calibration editing

Comprehensive unit conversion
Export data to .CSV (Excel readable)
Split large .IDE files
Convert .IDE files to MATLAB files

- Download Free Software

ORDERING INFORMATION

All products can be purchased online at mide.com. Additional shipping and ordering information is available here.

Included with each purchase:

Slam Stick Lab analysis software
6ft micro-USB cable
Mounting tape

Mounting bolts
User Manual and Quick Start Guide
N.I.S.T. Calibration Certification.

Appendix G

Instruction Manual for the Micro GPS Expander V4

Thank you for your purchase! This instruction manual will guide you through the installation and operation of your GPS

V4. Please read the entire manual carefully before proceeding. If, after you read the manual, you have further

questions or problems, see the Support page on http://www.eagletreesystems.com for additional information, or email us at support@eagletreesystems.com.

Intended Uses

The GPS Expander V4 (the GPS) is intended for recreational use exclusively in model planes, boats and cars. Other uses are not supported.

Features

The GPS is designed to be used with all present Eagle Tree recording, OSD, PowerPanel LCD, and wireless telemetry products. The GPS updates at 10Hz, consumes very little power, and has battery backup for quick hot and warm starts.

Our Data Recorder software includes support for Google Earth, including live mode display, and Google Earth Track support for logged data.

The GPS includes onboard filtering, as well as a toroid ring filter, to improve signal reception, especially when used in conjunction with First Person View video transmitters.

The GPS's built-in LED indicates when a 3D fix has been attained, for convenient usage. The LED flashes UNTIL a 3D fix is attained, then stops flashing.

The GPS is tiny and lightweight, making it perfect where weight and size are issues. See the Specifications section below for more information. With our Windows software, and now with Google Earth™ software, your GPS data can be easily and fully visualized.

Supported Products

The GPS is compatible with the Eagle Tree Systems eLogger V4/V3, Flight Data Recorder V2, Car Data Recorders and Boat Data Recorders with firmware version 5.55 or higher. It is also fully compatible with Seagull Dashboards with firmware version 4.76 or higher. If you have firmware lower than this version, go to our support website, and download the latest software, which will update the firmware of your device.

Packing List

Your package should include the following: the GPS, and a printed version of this manual. Please check your packaging for printed addenda to this manual which may be included if changes were made after printing.

How the GPS Works

When coupled The GPS uses satellite information to determine position, speed, altitude, course, distance to operator, and UTC time.

Connecting the GPS to the Recorder

The 4 wire connector attached to the GPS plugs into the rightmost port of your Data Recorder as shown in Figure 1. Make sure that you connect it in the correct location on the recorder, and with the correct polarity!

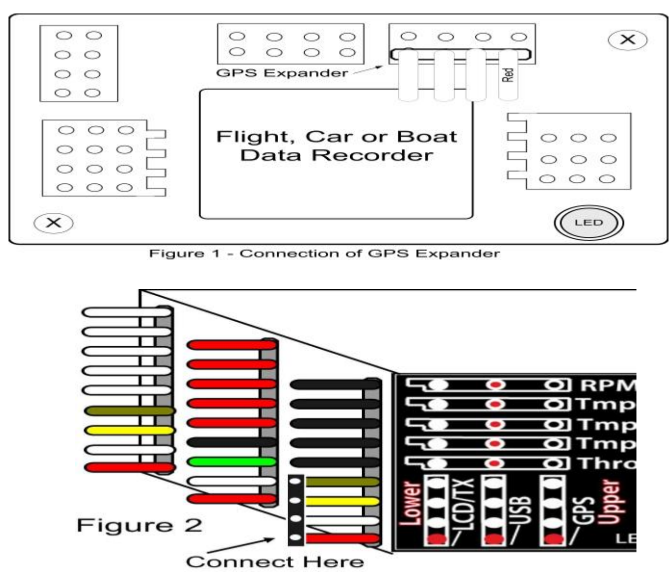


Figure G- 1Eagle Tree connection Diagram

Connecting the GPS to the eLogger V3/V4

The 4 wire connector attached to the GPS plugs into the eLogger V3/V4 as shown in. Make sure that you connect it in the correct location on the recorder, and with the correct polarity! Note: The GPS draws significant current from the eLogger. When the eLogger is powered by a higher voltage pack, such as an 8s or larger pack, or a pack above 30 volts, the eLogger's regulator may shut off after a short period when used with the GPS. If you find this is happening, please use our "Battery Backup Harness", part number CAB-BAT-BACK for the eLogger V3, or use the supplied throttle Y cable with your ELogger V4, to provide supplemental power to the eLogger if you encounter this issue.

Installing the GPS in your Model

The GPS should be mounted with Velcro in your vehicle so that the top part (with the label) is facing toward the sky. Normally, it is satisfactory to have the GPS inside the vehicle, since the skin of most vehicles is relatively thin. If you have difficulty getting a signal, try mounting it externally to the vehicle.

Setting up the GPS with your Recorder/eLogger

To use the GPS, first ensure that you have the latest version of the Windows application (the application). Application updates are available as a free download from the support page of our website, for our customers.

When configured with the recorder or eLogger, the GPS will log all GPS parameters as listed in the features section above, and the data is also available on the Seagull Wireless Dashboard, OSD Pro, PowerPanel, and EagleEyes (with PowerPanel option). Please see the instructions for these products for more information on GPS display.

If you wish to log GPS data, choose "Hardware, Choose Parameters to Log in the Recorder" in the app, and select "GPS Parameters". This indicates to the recorder that GPS data should be recorded. Note that you DO NOT need to record GPS data to see it live on the Seagull Dashboard.

If you wish the recorder to only start recording GPS (and all other) parameters after a GPS Fix is acquired, select "Advanced, Set Logging Triggers" and select the option to trigger on GPS Fix Acquire. NOTE: If this option is triggered, the LED will flash in "pause" state (two quick flashes repeated) until a fix is acquired. This is a handy way to tell when the fix has been acquired, if you do not use the Seagull Wireless Dashboard. Also note that the Recorder will not log any parameters if the GPS is not connected or has not acquired a fix, when this option is selected.

To configure the application to display the GPS data, choose "Software, Choose Instruments to Display on PC Screen" in the application, and select the GPS Parameters you wish to see. Here is a description of the parameters available:

GPS Coordinates – this option displays the Latitude and Longitude parameters of the flight. These parameters are displayed just below the playback controls in the application.

Show GPS In DMS Mode – when this checkbox is checked, the GPS Latitude and Longitude are displayed in Degrees:Minutes:Seconds.Seconds mode. When this box is unchecked, the parameters area displayed in Degrees:Minutes.Minutes (DDD.MM.MMMM) mode.

GPS UTC Time – this option displays the UTC time as received from the GPS. The UTC is displayed in the Total Length/Progress window when this option is selected.

GPS Altimeter Gauge/Numeric GPS Altitude – these options display GPS altitude. Note that GPS altitude takes several minutes to stabilize, after the GPS/recorder are powered. Also note that this altitude is above MSL (Mean Sea Level). Depending on the "Metric" button on this page, the altitude is displayed in either feet or meters.

GPS Speed Gauge/Numeric GPS Speed – these options display GPS speed. Depending on the "Metric" button on this page, the speed is displayed in either MPH or K/H.

GPS Course Gauge/Numeric GPS Course – these options display the course of the vehicle, in degrees True North.

GPS Distance to Operator – this option displays the distance from the operator to the GPS. The value is reset to zero when the GPS/recorder are powered on.

After a recording is made with the GPS, assuming GPS data is being logged, it will be displayed after data download. Note that if the recorder is connected to your PC via USB, Live Mode will allow you to see the GPS parameters live. Just hit the "Live Mode!" button. See the section below on graphing GPS data.

Setting up the GPS with the Seagull Dashboard or PowerPanel LCD

If you wish to display GPS data on your Seagull Dashboard, choose "Hardware, Choose Parameters to Display on Wireless Dashboard LCD" in the application, and select the GPS parameters you wish to display. For the PowerPanel LCD, select "Hardware, Choose Parameters to Display on PowerPanel."

After selecting the parameters, the LCD pages will show the GPS information you selected, as well as any other parameters selected. Note that the UTC, Lat/Lon and status parameters take up an entire LCD page each.

For the Dashboard, the GPS parameters can be selected via the Dashboard up/down buttons, as is the case with other Dashboard parameters.

If you connect your Dashboard to your laptop for real-time laptop display, the items selected in the section above will be displayed live.

NOTE: The GPS position data format is displayed as Degrees:Minutes.Minutes (DDD.MM.MMMM) (known as "GPS format") on the Dashboard and PowerPanel LCD. Some GPS programs display data in other formats, such as "Degrees:Minutes:Seconds" so you may need to convert between the two formats using an online tool.

Setting up the GPS with the Eagle Tree OSD Pro or OSD

If you wish to display GPS data on your Eagle Tree OSD, choose "Hardware, Choose Parameters to Display on Video OSD" in the application, and select the GPS parameters you wish to display.

After selecting the parameters, the OSD will display GPS information you selected, as well as any other parameters selected.

NOTE: The GPS position data format is displayed as Degrees:Minutes.Minutes (DDD.MM.MMMM) (known as “GPS format”) on the OSD Pro. Some GPS programs display data in other formats, such as “Degrees:Minutes:Seconds” so you may need to convert between the two formats using an online tool.

Using the GPS

Now that you have the GPS installed and configured, it’s time to use it! To use it, simply move the GPS into an open area (some enclosed areas will work also), power on your vehicle, and normally within one minute, the GPS will obtain a fix and begin recording and/or displaying information on the Seagull Dashboard.

The GPS has a built-in LED, which will flash UNTIL a 3D GPS fix is attained. Once a 3D fix is attained, the LED will turn OFF. This design is to save power, since the LED will be flashing only when a 3D fix is not attained. Note that if your GPS signal quality is not good, it is possible that you will attain a “2D” GPS fix. The LED will still blink, but the Eagle Tree equipment will still report a fix.

Note that the next time you power off and on your vehicle, the GPS should obtain a fix in as little as one second, assuming it hasn’t been relocated a great distance since power down.

Once a valid fix is received, the GPS data for that fix will be displayed on the Dashboard until the next fix comes in (normally once per second). If the Dashboard does not receive a new fix within a few seconds, it will mark the Lat and Lon fields with an “*” beside the values to indicate a “stale” fix.

If you are using the Dashboard, and have selected the GPS Status page to display, the Dashboard will display one of the following messages on the GPS Status page when it is selected:

“No GPS Detected” – this message indicates that the system has not detected a GPS. Check connection if this error message occurs.

“Acquiring Fix” – this message indicates that the GPS is connected and detected, but has not yet gotten a fix.

“Fix Acquired” – this message indicates that the GPS has acquired a valid fix (either 2D or 3D) within the last few seconds.

Note that if you set up the GPS Status page, and selected the “Beep four times when GPS fix is first acquired” option, the Dashboard will beep four times to indicate when a fix is first acquired.

Graphing GPS Data with Google Earth™

Our Windows application supports both Live Mode and recorded data output to Google Earth. Latitude, Longitude and Altitude (either GPS or barometric) data are output in the Google Earth format. NOTE: Please install Windows application version 8.87 or later from our website for full Google Earth support.

Google Earth™ Live Mode Support

To set up Google Earth Live Mode support, first select “Hardware, Live Mode Options”.

Check the “Click here to export Live Mode data to Google Earth” box if you wish to export Live Mode GPS data to Google Earth.

After clicking this box, you will be prompted to choose a Live Mode Google Earth path name. This is simply a path to a file, normally on your hard drive, to which Live Mode will record a Google Earth compatible file in real time. You will open this file in Google Earth also.

Check the “Click here to export Altimeter altitude readings to Google Earth” box if you have a Flight system, and wish to export your Recorder's Altimeter Sensor (barometric) altitude readings to Google Earth. Uncheck the box if you wish to send GPS Altitude data to Google Earth. Note that exported data will tell Google Earth whether the altitude values are barometric (altitude readings are zero at ground level) or whether they are absolute altitude from GPS (distance above MSL).

Once you have chosen the Google Earth options above, click “OK” on the Live Mode Options Dialog Box, and follow the steps below to see real time data from your GPS in Google Earth:

Install Google Earth version 5.2.1.1588 or later from the Google Earth Website http://earth.google.com/

Start Live Mode with the Eagle Tree Windows application – this can be done with either your Recorder, your EagleEyes, or with the Seagull Wireless Dashboard. Minimize the Windows application if desired. 3) In Google Earth, open the file that you specified above.

You should now see a live line graph of the GPS coordinates in Google Earth.

Google Earth™ Recorded Data Support

To save data in a Google Earth compatible format, simply download data from the Recorder, or capture Live Mode data, and click “File, Save for

Google Earth.”

The first time you save a file for Google Earth, the “Configure Google Earth File” page will appear. Check the “Click here to export Altimeter altitude readings to Google Earth” box if you have a Flight system, and wish to export your Recorder's Altimeter

Sensor (barometric) altitude readings to Google Earth. Uncheck the box if you wish to send GPS Altitude data to Google Earth. Note that exported data will tell Google Earth whether the altitude values are barometric (altitude readings are zero at ground level) or whether they are absolute altitude from GPS (distance above MSL).

Once you have saved the Google Earth compatible file, open the same file in Google Earth (version 5.2.1.1588 or later) and the path should be visible in Google Earth. Once loaded into Google Earth, all the powerful Google Earth visualization tools should be available with the data.

Note: With newer versions of Google Earth, if part or all of your session does not appear, it may be necessary to follow the procedure in Google Earth below. This procedure addresses an issue that occurs when the altimeter readings collected in your data are below Google Earth's determination of the local elevation. Google Earth does not display data points that are below this local elevation. Note that this issue is most common with surface applications, such as cars and boats.

load the KML file into Google Earth

right click on the KML file under the "Places" window • select the "Altitude" tab, and select "Relative to Ground".

Google Earth™ Track Support

To save data in a Google Earth Track compatible format, simply download data from the Recorder, or capture Live Mode data, and click "File, Save

Save as Google Earth Track."

The first time you save a file for Google Earth, the "Configure Google Earth File Save Settings" page will appear. Check the "Click here to export Altimeter altitude readings to Google Earth" box if you have a Flight system, and wish to export your Recorder's Altimeter Sensor (barometric) altitude readings to Google Earth. Uncheck the box if you wish to send GPS Altitude data to Google Earth. Note that exported data will tell Google Earth whether the altitude values are barometric (altitude readings are zero at ground level) or whether they are absolute altitude from GPS (distance above MSL).

Once you have saved the Google Earth Track compatible file, open the same file in Google Earth (version 5.2.1.1588) and the path should be visible in Google Earth. Once loaded into Google Earth, all the powerful Google Earth Track visualization tools should be available with the data.

Graphing GPS Data with the Eagle Tree Windows Application

The application supports a variety of Graphing options for GPS data, with both recorded and live data. NOTE: we recommend using Google Earth for GPS graphing other than simple 2D position graphing without a background image.

Recorded Mode Graphing

To Graph recorded data, first load the data into the app, either from downloading from the Recorder, recording from live mode with the Seagull Dashboard, or loading from a previously saved Data Recorder file. See the section below on graphing live mode data.

To Graph recorded GPS data in 2D, choose "Graph Data!", and select "2D GPS Chart." The chart will show the 2D (bird's eye) graph of the data, and will show the latitude and longitude positions on the axes. Note that the chart will automatically scale to fit the data.

To Graph recorded data in 3D, choose "Graph Data!", and select "3D GPS Chart." The Chart will show the 3D plot. The Z-Axis can be selected to be one or more of the following:

GPS Altitude

Barometric Altitude (For Boat or Flight Systems)

GPS Speed

Pitot/Static Speed (For Flight Systems)

These choices allow you to visualize your position as compared with your speed or altitude.

Loading a Background Image for 2D and 3D Charts

The graphing software supports loading an image upon which the GPS chart can be plotted. GPS background images with GPS coordinates can be obtained from Google Earth ™, GlobeExplorer.com™, or other internet resources. Electronic maps of the proper file format can also be loaded as background images, of course.

The software also supports setting the upper left-hand and lower right-hand GPS coordinates of the image. This is especially useful if you will be operating in a certain area, and wish to observe your vehicle's path over this particular area. Loading the GPS coordinates forces the chart to scale to the entered GPS coordinate rectangle, which causes the GPS data points to plot at the correct place within the image. Note that no points will be plotted if the current position of the GPS falls outside the rectangle formed by the coordinates you entered.

To load an image, first click the "Load Image" button, which will bring up the image "Load a GPS Chart Background Image" window. Then, click "Load GPS Chart Image." This allows you to load a JPEG, BMP, or GIF image file on 2D graphs. Currently only BMP files are supported in 3D GPS graphs, but support for more 3D image types will be added to a future version of the app.

To set the GPS coordinates of the image, enter the latitude and longitude of the upper left-hand corner of the image, and the lower right-hand corner of the image. These coordinates must be entered in signed decimal degrees (+/-DDD.DDDDDDD) format. Note that North and East coordinates are positive, and South and West coordinates are negative.

If you have only DMS coordinates, conversion from DMS to decimal can be done via a calculator, or from a conversion website. For example, if you have the following coordinates in DDD MM SSSS format, you would enter the corresponding coordinates into the application:

Upper Left-hand Image Coordinates in DMS: 33° 19’ 48.00” N 44° 26’ 24.00”E

Enter the following for Upper Left-hand Coordinates in decimal format: 33.330000 44.440000

Once the Background Image and optional GPS coordinates are entered, hit OK to load the image.

NOTE: currently, when a background image is loaded into a 3D GPS chart, another software program must have been used to correctly tilt and stretch the image. We will automatically tilt and stretch the image in a future version of the application.

Using GPS Charting in Live Mode

To view a 2D GPS chart of the vehicle’s real-time position, follow the below steps:

Connect either the Recorder or Seagull Dashboard to USB.

Launch the Application, and choose “Graph Data!, 2D GPS Chart.”

Load a background image if desired, if not already loaded.

Click the “Live Mode!” button on the application.

A live trail of the vehicle’s course should then appear on the 2D GPS chart.

Examining Data with Excel™ or compatible Spreadsheet Program

The GPS information is available in the .FDR (or .CDR or .BDR) files saved by the Windows Application, and these files can be viewed in Excel. Please see the instruction manual that came with your Recorder for information on how to load the files into Excel.

The GPS specific fields in the .FDR files are as follows:

GPSLat/GPSLon: GPS Latitude and Longitude (decimal format). Example: 42.56205667, -72.1795

GPSAlt: GPS Altitude (height above MSL, in either feet or meters, depending on your units selection). Example: 38.4

GPSSpeed: GPS Speed (either MPH or KPH, depending on your units selection). Example: 45

GPSCourse: True (not magnetic) Course, in degrees. Example: 341.1

GPSDist: Distance of GPS Module from where it got its first fix after system powerup (in either feet or meters, depending on unit selection). Example: 255

GPSUTC: UTC, converted to milliseconds. Example: 55928839

NumSats: Number of Satellites in view. Example: 4

GPSFlags: OR'd together flags of the following values: GPS Fix Valid: 1, 3D Fix: 2, GPS Data Received: 4. Example: 7

HDOP*10: This is the GPS's reported "HDOP" value, a measure of fix quality. Lower values are better. Note that a value of 1.2 will be indicated by "12" in this field

Locating a Lost Plane with the GPS

The combination of the Seagull Dashboard and GPS makes it easy to find lost planes. First, make sure you have selected Lat/Lon for display on the Dashboard.

The Dashboard always remembers the last valid fix received from the GPS, even when no signal is being received from the plane. To display the last valid fix, press the "Display Max" button on the Dashboard, and scroll to the Lat/Lon page. This will show the last valid fix received from your plane. To go to that location, use any handheld GPS unit (or another Seagull) to go to that location.

Troubleshooting

Below is a list of problems that may be encountered, and steps to remedy them. If your particular issue is not addressed by the below, see the Support page on http://eagletreesystems.com or email support@eagletreesystems.com. Include a full description of your problem, your machine configuration, brands/models of equipment, and Recorder firmware version if possible (from "Hardware, Firmware Control" in the application) and any other relevant details.

Problem: The data displayed on my OSD Pro, PowerPanel, or Seagull Dashboard does not seem to match my correct position, when the coordinates are entered into my mapping software

Solution: The GPS position data format is displayed as Degrees:Minutes.Minutes (DDD.MM.MMMM) (known as "GPS format") on the OSD Pro, PowerPanel, and Seagull. Some GPS programs expect the coordinates in other formats, such as "Degrees:Minutes:Seconds" so you may need to convert between the two formats using an online tool, such as the one at: http://www.csgnetwork.com/gpscoordconv.html

Problem: The GPS Module does not appear to be getting a signal.   The LED on the GPS Module always blinks. When I download data or look at the data on the Seagull, the data consist of zeros.   The GPS Status on the Dashboard or Laptop displays "Acquiring Fix" but it never acquires.

Solution: If you are trying to record GPS data, make sure you have selected logging of GPS data as described in the setup section above.

Solution: If you are using the Seagull system, and are not getting "No Signal" messages, see the Seagull manual.   If you are getting a signal, but no GPS data, try the above steps.

Solution: Make sure that the GPS has a reasonably unobstructed view of the sky.

Problem: The Dashboard displays "No GPS Detected" on the GPS Status LCD Page.

Solution: Make sure you have the GPS connected correctly to the recorder, and make sure that no wires are cut. Solution: Power down the system, wait 15 seconds, and reapply power.

Problem: The Dashboard displays "Acquiring Fix" on the Lat/Lon LCD Page for more than about 5 minutes.

Solution: Make sure that the GPS has a reasonably unobstructed view of the sky.

Solution: Make sure you have gotten a valid fix before the vehicle starts moving. Moving slows down the acquisition process considerably. Solution: Some areas have lots of RF Noise, which can increase the length of time required to get a fix.   Solution: On cloudy days, it will take longer to get a fix than on clear days.

Problem: My eLogger V3 shuts off or the LED flashes rapidly when used with the GPS.

Solution: The GPS draws significant current from the eLogger. When the eLogger is powered by a higher voltage pack, such as an 8s or larger pack, or a pack above 30 volts, the eLogger's regulator may shut off after a short period when used with the GPS. Please use our "Battery Backup Harness", part number CAB-BAT-BACK, to provide supplemental power to the eLogger, if you encounter this issue.

GPS Specifications (subject to change)

Update Rate: 10Hz

Cable Length: 11" (28cm)

Antenna: Built-In patch

WAAS and EGNOS support

Built-in battery backup for fast fix reacquisition

Time to Fix: 1 second hot, 36 second cold (typ)

Speed Accuracy approx 0.1 m/s

Current draw: less than 40 mA when tracking

Dimensions: approx 1.4” x 0.9” x 0.3” (35x20x8mm)

Weighs approx 0.4 oz (11g)

Position accuracy approx 8.2 ft (2.5m) CEP with WAAS/EGNOS

Sensitivity: approx -165dBm

Datum: WGS84

Regulatory

The GPS has been tested in typical installations and was found to comply with the emission and immunity requirements of the EU. As with any change or addition to an R/C system, you are strongly advised to carry out a range and performance check before operating the equipment.

Limited Warranty

Eagle Tree Systems, LLC, warrants the GPS to be free from defects in materials and workmanship for a period of one (1) year from the date of original purchase. This warranty is nontransferable. If your unit requires warranty service during this period, we will replace or repair it at our option. Shipping cost to us is your responsibility.

To obtain warranty service, contact us by phone, fax or email to request an RMA number.

No returns will be accepted without this number.

This limited warranty does not cover:

The Software included with the System. See the Software license agreement for more information on Software restrictions.

Problems that result from:

External causes such as accident, abuse, misuse, or problems with electrical power

Servicing not authorized by us

Usage that is not in accordance with product instructions

Failure to follow the product instructions

THIS WARRANTY GIVES YOU SPECIFIC LEGAL RIGHTS, AND YOU MAY ALSO HAVE OTHER RIGHTS WHICH VARY FROM STATE

TO STATE (OR JURISDICTION TO JURISDICTION). OUR RESPONSIBILITY FOR MALFUNCITONS AND DEFECTS IN HARDWARE IS

LIMITED TO REPAIR AND REPLACEMENT AS SET FORTH IN THIS WARRANTY STATEMENT. ALL EXPRESS AND IMPLIED

WARRANTIES FOR THE PRODUCT, INCLUDING, BUT NOT LIMITED TO, ANY IMPLIED WARRANTIES AND CONDITIONS OF

MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE, ARE LIMITED IN TIME TO THE TERM OF THE LIMITED

WARRANTY PERIOD AS DESCRIBED ABOVE. NO WARRANTIES, WHETHER EXPRESS OR IMPLIED, WILL APPLY AFTER THE LIMITED WARRANTY PERIOD HAS EXPIRED. SOME STATES DO NOT ALLOW LIMITATIONS ON HOW LONG AN IMPLIED WARRANTY LASTS, SO THIS LIMITATION MAY NOT APPLY TO YOU.

WE DO NOT ACCEPT LIABILITY BEYOND THE REMEDIES PROVIDED FOR IN THIS LIMITED WARRANTY OR FOR

CONSEQUENTIAL OR INCIDENTAL DAMAGES, INCLUDING, WITHOUT LIMITATION, ANY LIABILTY FOR THIRD-PARTY CLAIMS AGAINST YOU FOR DAMAGES, FOR PRODUCTS NOT BEING AVAILABLE FOR USE, OR FOR LOST DATA OR LOST SOFTWARE. OUR LIABILITY WILL BE NO MORE THAN THE AMOUNT YOU PAID FOR THE PRODUCT THAT IS THE SUBJECT OF A CLAIM. THIS IS THE MAXIMUM AMOUNT FOR WHICH WE ARE RESPONSIBLE.

SOME STATES DO NOT ALLOW THE EXCLUSION OR LIMITATION OF INCIDENTAL OR CONSEQUENTIAL DAMAGES, SO THE ABOVE LIMITATION OR EXCLUSION MAY NOT APPLY TO YOU.

Appendix H

Pre- testing check have to be done before testing the following sample of boat check list before testing:

Check the boat leakage

Make sure spring stiffness (high, low spring rates), prepare more than one for each spring rate to be able to increase stiffness by using double if needed

Install boat fines

Check the cooling circuit

Charge 3 pairs of Lipo Batteries

Make equivalent weight to compensate different batteries weights

Make sure transmitter Batteries are good and have spare

Check propellant shaft maintenance and lubrication

Check the data logger wiring

Make sure GPS working inside the boat while it covered

(Small orifice diameter, high viscous oil&large orifice, low viscous oil)

Prepare two shock absorber

13-Make sure Lap top battery is charged to be able to download the data

14-Weight the boat and mark the CG

Appendix I

Model analytical equations

$$
\begin{aligned}
\text{F1} = {} & (-Mg + (F1x\text{n}3) + (F2 * n3) + (F3 * n4) + (F4 * n4)).\overrightarrow{{}^{N}v_1}^{A} \\
& + (moment1.\overrightarrow{{}^{N}\omega_1}^{A} + (moment2.\overrightarrow{{}^{N}\omega_1}^{A}) + (moment3.\overrightarrow{{}^{N}\omega_1}^{A}) \\
& + (moment4.\overrightarrow{{}^{N}\omega_1}^{A}) + (-mg + \text{F1} * \text{n3}).\overrightarrow{{}^{N}v_1}^{B1} (moment1.\overrightarrow{{}^{N}\omega_1}^{B1}) \\
& + (springmoment1.\overrightarrow{{}^{N}\omega_1}^{B1}) + (dampermoment1.\overrightarrow{{}^{N}\omega_1}^{B1}) \\
& + (-mg + \text{F2}x\text{n3}).\overrightarrow{{}^{N}v_1}^{B2} + (moment2.\overrightarrow{{}^{N}\omega_1}^{B2} \\
& + \left(springmoment2.\overrightarrow{{}^{N}\omega_1}^{B2}\right) + \left(dampermoment2.\overrightarrow{{}^{N}\omega_1}^{B2}\right) \\
& + \quad (-mxg + \text{F3}x\text{n3}).\overrightarrow{{}^{N}v_1}^{B3} + \left(moment3.\overrightarrow{{}^{N}\omega_1}^{B3}\right) \\
& + \left(springmoment3.\overrightarrow{{}^{N}\omega_1}^{B3}\right) + (-mxg + \text{F4}x\text{n3}).\overrightarrow{{}^{N}v_1}^{B4} \\
& + \left(\text{moment4}.\overrightarrow{{}^{N}\omega_1}^{B4}\right) + \left(springmoment4.\overrightarrow{{}^{N}\omega_1}^{B4}\right) \\
& + \left(dampermoment4.\overrightarrow{{}^{N}\omega_1}^{B4}\right)
\end{aligned}
$$

$$
\begin{aligned}
\text{F2} = {} & (-Mg + (F1x\text{n}3) + (F2 * n3) + (F3 * n4) + (F4 * n4)).\overrightarrow{{}^{N}v_2}^{A} \\
& + (moment1.\overrightarrow{{}^{N}\omega_2}^{A} + (moment2.\overrightarrow{{}^{N}\omega_2}^{A}) + (moment3.\overrightarrow{{}^{N}\omega_2}^{A}) \\
& + (moment4.\overrightarrow{{}^{N}\omega_2}^{A}) + (-mg + \text{F1} * \text{n3}).\overrightarrow{{}^{N}v_2}^{B1} (moment1.\overrightarrow{{}^{N}\omega_2}^{B1}) \\
& + (springmoment1.\overrightarrow{{}^{N}\omega_2}^{B1}) + (dampermoment1.\overrightarrow{{}^{N}\omega_2}^{B1}) \\
& + (-mg + \text{F2}x\text{n3}).\overrightarrow{{}^{N}v_2}^{B2} + (moment2.\overrightarrow{{}^{N}\omega_2}^{B2} \\
& + \left(springmoment2.\overrightarrow{{}^{N}\omega_2}^{B2}\right) + \left(dampermoment2.\overrightarrow{{}^{N}\omega_2}^{B2}\right) \\
& + \quad (-mxg + \text{F3}x\text{n3}).\overrightarrow{{}^{N}v_2}^{B3} + \left(moment3.\overrightarrow{{}^{N}\omega_2}^{B3}\right) \\
& + \left(springmoment3.\overrightarrow{{}^{N}\omega_2}^{B3}\right) + (-mxg + \text{F4}x\text{n3}).\overrightarrow{{}^{N}v_2}^{B4} \\
& + \left(\text{moment4}.\overrightarrow{{}^{N}\omega_2}^{B4}\right) + \left(springmoment4.\overrightarrow{{}^{N}\omega_2}^{B4}\right) \\
& + \left(dampermoment4.\overrightarrow{{}^{N}\omega_2}^{B4}\right)
\end{aligned}
$$

$$
\begin{aligned}
F3 = {} & (-Mg + (F1xn3) + (F2 * n3) + (F3 * n4) + (F4 * n4)).\overrightarrow{{}^{N}v_3}^{A} \\
& + (moment1.\overrightarrow{{}^{N}\omega_3}^{A} + (moment2.\overrightarrow{{}^{N}\omega_3}^{A}) + (moment3.\overrightarrow{{}^{N}\omega_3}^{A}) \\
& + (moment4.\overrightarrow{{}^{N}\omega_3}^{A}) + (-mg + \mathrm{F1} * \mathrm{n3}).\overrightarrow{{}^{N}v_3}^{B1} (moment1.\overrightarrow{{}^{N}\omega_3}^{B1}) \\
& + (springmoment1.\overrightarrow{{}^{N}\omega_3}^{B1}) + (dampermoment1.\overrightarrow{{}^{N}\omega_3}^{B1}) \\
& + (-mg + \mathrm{F2}x\mathrm{n3}).\overrightarrow{{}^{N}v_3}^{B2} + (moment2.\overrightarrow{{}^{N}\omega_3}^{B2} \\
& + \left(springmoment2.\overrightarrow{{}^{N}\omega_3}^{B2}\right) + \left(dampermoment2.\overrightarrow{{}^{N}\omega_3}^{B2}\right) \\
& + \quad (-mxg + \mathrm{F3}x\mathrm{n3}).\overrightarrow{{}^{N}v_3}^{B3} + \left(moment3.\overrightarrow{{}^{N}\omega_3}^{B3}\right) \\
& + \left(springmoment3.\overrightarrow{{}^{N}\omega_3}^{B3}\right) + (-mxg + \mathrm{F4}x\mathrm{n3}).\overrightarrow{{}^{N}v_3}^{B4} \\
& + \left(\mathrm{moment4}.\overrightarrow{{}^{N}\omega_3}^{B4}\right) + \left(springmoment4.\overrightarrow{{}^{N}\omega_3}^{B4}\right) \\
& + \left(dampermoment4.\overrightarrow{{}^{N}\omega_3}^{B4}\right)
\end{aligned}
$$

$$
\begin{aligned}
F4 = {} & (-Mg + (F1xn3) + (F2 * n3) + (F3 * n4) + (F4 * n4)).\overrightarrow{{}^{N}v_4}^{A} \\
& + (moment1.\overrightarrow{{}^{N}\omega_4}^{A} + (moment2.\overrightarrow{{}^{N}\omega_4}^{A}) + (moment3.\overrightarrow{{}^{N}\omega_4}^{A}) \\
& + (moment4.\overrightarrow{{}^{N}\omega_4}^{A}) + (-mg + \mathrm{F1} * \mathrm{n3}).\overrightarrow{{}^{N}v_4}^{B1} (moment1.\overrightarrow{{}^{N}\omega_4}^{B1}) \\
& + (springmoment1.\overrightarrow{{}^{N}\omega_4}^{B1}) + (dampermoment1.\overrightarrow{{}^{N}\omega_4}^{B1}) \\
& + (-mg + \mathrm{F2}x\mathrm{n3}).\overrightarrow{{}^{N}v_4}^{B2} + (moment2.\overrightarrow{{}^{N}\omega_4}^{B2} \\
& + \left(springmoment2.\overrightarrow{{}^{N}\omega_4}^{B2}\right) + \left(dampermoment2.\overrightarrow{{}^{N}\omega_4}^{B2}\right) \\
& + \quad (-mxg + \mathrm{F3}x\mathrm{n3}).\overrightarrow{{}^{N}v_4}^{B3} + \left(moment3.\overrightarrow{{}^{N}\omega_4}^{B3}\right) \\
& + \left(springmoment3.\overrightarrow{{}^{N}\omega_4}^{B3}\right) + (-mxg + \mathrm{F4}x\mathrm{n3}).\overrightarrow{{}^{N}v_4}^{B4} \\
& + \left(\mathrm{moment4}.\overrightarrow{{}^{N}\omega_4}^{B4}\right) + \left(springmoment4.\overrightarrow{{}^{N}\omega_4}^{B4}\right) \\
& + \left(dampermoment4.\overrightarrow{{}^{N}\omega_4}^{B4}\right)
\end{aligned}
$$

$$
\begin{aligned}
\mathrm{F5} = {} & (-Mg + (F1x\mathrm{n}3) + (F2 * n3) + (F3 * n4) + (F4 * n4)).\overrightarrow{{}^{N}v_{5}}^{A} \\
& + (moment1.\overrightarrow{{}^{N}\omega_{5}}^{A} + (moment2.\overrightarrow{{}^{N}\omega_{5}}^{A}) + (moment3.\overrightarrow{{}^{N}\omega_{5}}^{A}) \\
& + (moment4.\overrightarrow{{}^{N}\omega_{5}}^{A}) + (-mg + \mathrm{F1} * \mathrm{n3}).\overrightarrow{{}^{N}v_{5}}^{B1} (moment1.\overrightarrow{{}^{N}\omega_{5}}^{B1}) \\
& + (springmoment1.\overrightarrow{{}^{N}\omega_{5}}^{B1}) + (dampermoment1.\overrightarrow{{}^{N}\omega_{5}}^{B1}) \\
& + (-mg + \mathrm{F2}x\mathrm{n3}).\overrightarrow{{}^{N}v_{5}}^{B2} + (moment2.\overrightarrow{{}^{N}\omega_{5}}^{B2} \\
& + \left(springmoment2.\overrightarrow{{}^{N}\omega_{5}}^{B2}\right) + \left(dampermoment2.\overrightarrow{{}^{N}\omega_{5}}^{B2}\right) \\
& + \quad (-mxg + \mathrm{F3}x\mathrm{n3}).\overrightarrow{{}^{N}v_{5}}^{B3} + \left(moment3.\overrightarrow{{}^{N}\omega_{5}}^{B3}\right) \\
& + \left(springmoment3.\overrightarrow{{}^{N}\omega_{5}}^{B3}\right) + (-mxg + \mathrm{F4}x\mathrm{n3}).\overrightarrow{{}^{N}v_{5}}^{B4} \\
& + \left(\mathrm{moment4}.\overrightarrow{{}^{N}\omega_{5}}^{B4}\right) + \left(springmoment4.\overrightarrow{{}^{N}\omega_{5}}^{B4}\right) \\
& + \left(dampermoment4.\overrightarrow{{}^{N}\omega_{5}}^{B4}\right)
\end{aligned}
$$

$$
\begin{aligned}
\mathrm{F6} = {} & (-Mg + (F1x\mathrm{n}3) + (F2 * n3) + (F3 * n4) + (F4 * n4)).\overrightarrow{{}^{N}v_{6}}^{A} \\
& + (moment1.\overrightarrow{{}^{N}\omega_{6}}^{A} + (moment2.\overrightarrow{{}^{N}\omega_{6}}^{A}) + (moment3.\overrightarrow{{}^{N}\omega_{6}}^{A}) \\
& + (moment4.\overrightarrow{{}^{N}\omega_{6}}^{A}) + (-mg + \mathrm{F1} * \mathrm{n3}).\overrightarrow{{}^{N}v_{6}}^{B1} (moment1.\overrightarrow{{}^{N}\omega_{6}}^{B1}) \\
& + (springmoment1.\overrightarrow{{}^{N}\omega_{6}}^{B1}) + (dampermoment1.\overrightarrow{{}^{N}\omega_{6}}^{B1}) \\
& + (-mg + \mathrm{F2}x\mathrm{n3}).\overrightarrow{{}^{N}v_{6}}^{B2} + (moment2.\overrightarrow{{}^{N}\omega_{6}}^{B2} \\
& + \left(springmoment2.\overrightarrow{{}^{N}\omega_{6}}^{B2}\right) + \left(dampermoment2.\overrightarrow{{}^{N}\omega_{6}}^{B2}\right) \\
& + \quad (-mxg + \mathrm{F3}x\mathrm{n3}).\overrightarrow{{}^{N}v_{6}}^{B3} + \left(moment3.\overrightarrow{{}^{N}\omega_{6}}^{B3}\right) \\
& + \left(springmoment3.\overrightarrow{{}^{N}\omega_{6}}^{B3}\right) + (-mxg + \mathrm{F4}x\mathrm{n3}).\overrightarrow{{}^{N}v_{6}}^{B4} \\
& + \left(\mathrm{moment4}.\overrightarrow{{}^{N}\omega_{6}}^{B4}\right) + \left(springmoment4.\overrightarrow{{}^{N}\omega_{6}}^{B4}\right) \\
& + \left(dampermoment4.\overrightarrow{{}^{N}\omega_{6}}^{B4}\right)
\end{aligned}
$$

$$
\begin{aligned}
\mathrm{F7} = {} & (-Mg + (F1x\mathrm{n}3) + (F2 * n3) + (F3 * n4) + (F4 * n4)).\overrightarrow{{}^{N}v_7}^{A} \\
& + (moment1.\overrightarrow{{}^{N}\omega_7}^{A} + (moment2.\overrightarrow{{}^{N}\omega_7}^{A}) + (moment3.\overrightarrow{{}^{N}\omega_7}^{A}) \\
& + (moment4.\overrightarrow{{}^{N}\omega_7}^{A}) + (-mg + \mathrm{F1} * \mathrm{n3}).\overrightarrow{{}^{N}v_7}^{B1} (moment1.\overrightarrow{{}^{N}\omega_7}^{B1}) \\
& + (springmoment1.\overrightarrow{{}^{N}\omega_7}^{B1}) + (dampermoment1.\overrightarrow{{}^{N}\omega_7}^{B1}) \\
& + (-mg + \mathrm{F2}x\mathrm{n3}).\overrightarrow{{}^{N}v_7}^{B2} + (moment2.\overrightarrow{{}^{N}\omega_7}^{B2} \\
& + \left(springmoment2.\overrightarrow{{}^{N}\omega_7}^{B2}\right) + \left(dampermoment2.\overrightarrow{{}^{N}\omega_7}^{B2}\right) \\
& + \quad (-mxg + \mathrm{F3}x\mathrm{n3}).\overrightarrow{{}^{N}v_7}^{B3} + \left(moment3.\overrightarrow{{}^{N}\omega_7}^{B3}\right) \\
& + \left(springmoment3.\overrightarrow{{}^{N}\omega_7}^{B3}\right) + (-mxg + \mathrm{F4}x\mathrm{n3}).\overrightarrow{{}^{N}v_7}^{B4} \\
& + \left(\mathrm{moment4}.\overrightarrow{{}^{N}\omega_7}^{B4}\right) + \left(springmoment4.\overrightarrow{{}^{N}\omega_7}^{B4}\right) \\
& + \left(dampermoment4.\overrightarrow{{}^{N}\omega_7}^{B4}\right)
\end{aligned}
$$

$$
\begin{aligned}
\mathrm{F8} = {} & (-Mg + (F1x\mathrm{n}3) + (F2 * n3) + (F3 * n4) + (F4 * n4)).\overrightarrow{{}^{N}v_8}^{A} \\
& + (moment1.\overrightarrow{{}^{N}\omega_8}^{A} + (moment2.\overrightarrow{{}^{N}\omega_8}^{A}) + (moment3.\overrightarrow{{}^{N}\omega_8}^{A}) \\
& + (moment4.\overrightarrow{{}^{N}\omega_8}^{A}) + (-mg + \mathrm{F1} * \mathrm{n3}).\overrightarrow{{}^{N}v_8}^{B1} (moment1.\overrightarrow{{}^{N}\omega_8}^{B1}) \\
& + (springmoment1.\overrightarrow{{}^{N}\omega_8}^{B1}) + (dampermoment1.\overrightarrow{{}^{N}\omega_8}^{B1}) \\
& + (-mg + \mathrm{F2}x\mathrm{n3}).\overrightarrow{{}^{N}v_8}^{B2} + (moment2.\overrightarrow{{}^{N}\omega_8}^{B2} \\
& + \left(springmoment2.\overrightarrow{{}^{N}\omega_8}^{B2}\right) + \left(dampermoment2.\overrightarrow{{}^{N}\omega_8}^{B2}\right) \\
& + \quad (-mxg + \mathrm{F3}x\mathrm{n3}).\overrightarrow{{}^{N}v_8}^{B3} + \left(moment3.\overrightarrow{{}^{N}\omega_8}^{B3}\right) \\
& + \left(springmoment3.\overrightarrow{{}^{N}\omega_8}^{B3}\right) + (-mxg + \mathrm{F4}x\mathrm{n3}).\overrightarrow{{}^{N}v_8}^{B4} \\
& + \left(\mathrm{moment4}.\overrightarrow{{}^{N}\omega_8}^{B4}\right) + \left(springmoment4.\overrightarrow{{}^{N}\omega_8}^{B4}\right) \\
& + \left(dampermoment4.\overrightarrow{{}^{N}\omega_8}^{B4}\right)
\end{aligned}
$$

$$
\begin{aligned}
\mathrm{F9} = {} & (-Mg + (F1x\mathrm{n}3) + (F2 * n3) + (F3 * n4) + (F4 * n4)).\overrightarrow{{}^{N}v_{9}}^{A} \\
& + (moment1.\overrightarrow{{}^{N}\omega_{9}}^{A} + (moment2.\overrightarrow{{}^{N}\omega_{9}}^{A}) + (moment3.\overrightarrow{{}^{N}\omega_{9}}^{A}) \\
& + (moment4.\overrightarrow{{}^{N}\omega_{9}}^{A}) + (-mg + \mathrm{F1} * \mathrm{n3}).\overrightarrow{{}^{N}v_{9}}^{B1} (moment1.\overrightarrow{{}^{N}\omega_{9}}^{B1}) \\
& + (springmoment1.\overrightarrow{{}^{N}\omega_{9}}^{B1}) + (dampermoment1.\overrightarrow{{}^{N}\omega_{9}}^{B1}) \\
& + (-mg + \mathrm{F2}x\mathrm{n3}).\overrightarrow{{}^{N}v_{9}}^{B2} + (moment2.\overrightarrow{{}^{N}\omega_{9}}^{B2} \\
& + \left(springmoment2.\overrightarrow{{}^{N}\omega_{9}}^{B2}\right) + \left(dampermoment2.\overrightarrow{{}^{N}\omega_{9}}^{B2}\right) \\
& + (-mxg + \mathrm{F3}x\mathrm{n3}).\overrightarrow{{}^{N}v_{9}}^{B3} + \left(moment3.\overrightarrow{{}^{N}\omega_{9}}^{B3}\right) \\
& + \left(springmoment3.\overrightarrow{{}^{N}\omega_{9}}^{B3}\right) + (-mxg + \mathrm{F4}x\mathrm{n3}).\overrightarrow{{}^{N}v_{9}}^{B4} \\
& + \left(\mathrm{moment4}.\overrightarrow{{}^{N}\omega_{9}}^{B4}\right) + \left(springmoment4.\overrightarrow{{}^{N}\omega_{9}}^{B4}\right) \\
& + \left(dampermoment4.\overrightarrow{{}^{N}\omega_{9}}^{B4}\right)
\end{aligned}
$$

$$
\begin{aligned}
\mathrm{F10} = {} & (-Mg + (F1x\mathrm{n}3) + (F2 * n3) + (F3 * n4) + (F4 * n4)).\overrightarrow{{}^{N}v_{10}}^{A} \\
& + (moment1.\overrightarrow{{}^{N}\omega_{10}}^{A} + (moment2.\overrightarrow{{}^{N}\omega_{10}}^{A}) + (moment3.\overrightarrow{{}^{N}\omega_{10}}^{A}) \\
& + (moment4.\overrightarrow{{}^{N}\omega_{10}}^{A}) + (-mg + \mathrm{F1} * \mathrm{n3}).\overrightarrow{{}^{N}v_{10}}^{B1} (moment1.\overrightarrow{{}^{N}\omega_{10}}^{B1}) \\
& + (springmoment1.\overrightarrow{{}^{N}\omega_{10}}^{B1}) + (dampermoment1.\overrightarrow{{}^{N}\omega_{10}}^{B1}) \\
& + (-mg + \mathrm{F2}x\mathrm{n3}).\overrightarrow{{}^{N}v_{10}}^{B2} + (moment2.\overrightarrow{{}^{N}\omega_{10}}^{B2} \\
& + \left(springmoment2.\overrightarrow{{}^{N}\omega_{10}}^{B2}\right) + \left(dampermoment2.\overrightarrow{{}^{N}\omega_{10}}^{B2}\right) \\
& + (-mxg + \mathrm{F3}x\mathrm{n3}).\overrightarrow{{}^{N}v_{10}}^{B3} + \left(moment3.\overrightarrow{{}^{N}\omega_{10}}^{B3}\right) \\
& + \left(springmoment3.\overrightarrow{{}^{N}\omega_{10}}^{B3}\right) + (-mxg + \mathrm{F4}x\mathrm{n3}).\overrightarrow{{}^{N}v_{10}}^{B4} \\
& + \left(\mathrm{moment4}.\overrightarrow{{}^{N}\omega_{10}}^{B4}\right) + \left(springmoment4.\overrightarrow{{}^{N}\omega_{10}}^{B4}\right) \\
& + \left(dampermoment4.\overrightarrow{{}^{N}\omega_{10}}^{B4}\right)
\end{aligned}
$$

Mathematical on Model Mathematica Code

```
xt=x[t];
yt=y[t];
zt=z[t];
tht=th[t];
 phit=phi[t];
psit=psi[t];
tht1=th1[t];
tht2=th2[t];
tht3=th3[t];
tht4=th4[t];
u1=D[xt,t];
u2=D[yt,t];
u3=D[zt,t];
u4=D[tht,t];
u5=D[phit,t];
u6=D[psit,t];
u7=D[tht1,t];
u8=D[tht2,t];
u9=D[tht3,t];
u10=D[tht4,t];

(* global coordinates *)
n1={1,0,0}; n2={0,1,0}; n3={0,0,1};
(* Body coordinates to glabal coordinate *)
b1=Cos[psit] Cos[tht]*n1+Cos[tht] Sin[psit]*n2-Sin[tht]*n3
```

b2=(-Cos[phit] Sin[psit]+Cos[psit] Sin[phit] Sin[tht])*n1+(Cos[phit] Cos[psit]+Sin[phit] Sin[psit] Sin[tht])*n2+(Cos[tht] Sin[phit])*n3

b3=(Sin[phit] Sin[psit]+Cos[phit] Cos[psit] Sin[tht])*n1+(-Cos[psit] Sin[phit]+Cos[phit] Sin[psit] Sin[tht])*n2+(Cos[phit] Cos[tht])*n3

{Cos[psi[t]] Cos[th[t]],Cos[th[t]] Sin[psi[t]],-Sin[th[t]]}

{-Cos[phi[t]] Sin[psi[t]]+Cos[psi[t]] Sin[phi[t]] Sin[th[t]],Cos[phi[t]] Cos[psi[t]]+Sin[phi[t]] Sin[psi[t]] Sin[th[t]],Cos[th[t]] Sin[phi[t]]}

{Sin[phi[t]] Sin[psi[t]]+Cos[phi[t]] Cos[psi[t]] Sin[th[t]],-Cos[psi[t]] Sin[phi[t]]+Cos[phi[t]] Sin[psi[t]] Sin[th[t]],Cos[phi[t]] Cos[th[t]]}

(* sponson coordinates to global cor front left(1) sponson then front right(2)-rear left(3)-rear right(4) *)

s1=Cos[tht1]*b1+Sin[tht1]*b3;

s2=b2;

s3=-Sin[tht1]*b1+Cos[tht1]*b3;

(* sponson coordinates to global cor front RIGHT(1) sponson then front right(2)-rear left(3)-rear right(4) *)

s21=Cos[tht2]*b1+Sin[tht2]*b3;

s22=b2;

s23=-Sin[tht2]*b1+Cos[tht2]*b3;

(* sponson coordinates to global cor front left REAR(1) sponson then front right(2)-rear left(3)-rear right(4) *)

s31=Cos[tht3]*b1+Sin[tht3]*b3;

s32=b2;

s33=-Sin[tht3]*b1+Cos[tht3]*b3;

(* sponson coordinates to global cor front RIGHT REAR(1) sponson then front right(2)-rear left(3)-rear right(4) *)

s41=Cos[tht4]*b1+Sin[tht4]*b3;

s42=b2;

s43=-Sin[tht4]*b1+Cos[tht4]*b3;

(* Front joint position *)

x0=xt*n1+yt*n2+zt*n3;

```
xrf=x0+a1*b1+a2*b3;

xrr=x0+a3*b1+a4*b3;

(* "Position of CG of sponson:"  *)

x1=xrf-a5*s1-a6*s2-a7*s3;

x2=xrf-a5*s21+a6*s22-a7*s23;

x3=xrr-a8*s31-a9*s32-a10*s33;

x4=xrr-a8*s41+a9*s42-a10*s43;

(*linear velocity of the hull*)

Vh=D[x0,t];

(*angular velocity of the hull*)

wh=(u5-u6*Sin[tht])*n1+(u4*Cos[phit]+u6*Cos[tht]*Sin[phit])*n2+(-
u4*Sin[phit]+u6*Cos[tht]*Cos[phit])*n3;

(*linear velocity of the sponson*)

vs1=D[x1,t];

vs2=D[x2,t];

vs3=D[x3,t];

vs4=D[x4,t];

(*angular velocity of sponson*)

wB1=wh-u7*b2;

wB2=wh-u8*b2;

wB3=wh-u9*b2;

wB4=wh-u10*b2;

(*linear acceleration of the hull*)

aH=D[Vh,t];

(*angular acceleration of the hull*)

alfaH=D[wh,t];

(*angular acceleration of the sponson*)

alafaS1=D[wB1,t];

alafaS2=D[wB2,t];
```

```
alafaS3=D[wB3,t];
alafaS4=D[wB4,t];
(*linear acceleration of the sponson*)
aS1=D[vs1,t];
aS2=D[vs2,t];
aS3=D[vs3,t];
aS4=D[vs4,t];
(* partial velocities and partial angular velocities *
rvA1=D[Vh,u1];
rvA2=D[Vh,u2];
rvA3=D[Vh,u3];
rvA4=D[Vh,u4];
rvA5=D[Vh,u5];
rvA6=D[Vh,u6];
rvA7=D[Vh,u7];
rvA8=D[Vh,u8];
rvA9=D[Vh,u9];
rvA10=D[Vh,u10];
rwA1=D[wh,u1];
rwA2=D[wh,u2];
rwA3=D[wh,u3];
rwA4=D[wh,u4];
rwA5=D[wh,u5];
rwA6=D[wh,u6];
rwA7=D[wh,u7];
rwA8=D[wh,u8];
rwA9=D[wh,u9];
rwA10=D[wh,u10];
```

```
rvB1=D[vs1,u1];
rvB2=D[vs1,u2];
rvB3=D[vs1,u3];
rvB4=D[vs1,u4];
rvB5=D[vs1,u5];
rvB6=D[vs1,u6];
rvB7=D[vs1,u7];
rvB8=D[vs1,u8];
rvB9=D[vs1,u9];
rvB10=D[vs1,u10];
rvB21=D[vs2,u1];
rvB22=D[vs2,u2];
rvB23=D[vs2,u3];
rvB24=D[vs2,u4];
rvB25=D[vs2,u5];
rvB26=D[vs2,u6];
rvB27=D[vs2,u7];
rvB28=D[vs2,u8];
rvB29=D[vs2,u9];
rvB210=D[vs2,u10];
rvB31=D[vs3,u1];
rvB32=D[vs3,u2];
rvB33=D[vs3,u3];
rvB34=D[vs3,u4];
rvB35=D[vs3,u5];
rvB36=D[vs3,u6];
rvB37=D[vs3,u7];
rvB38=D[vs3,u8];
```

```
rvB39=D[vs3,u9];
rvB310=D[vs3,u10];
rvB41=D[vs4,u1];
rvB42=D[vs4,u2];
rvB43=D[vs4,u3];
rvB44=D[vs4,u4];
rvB45=D[vs4,u5];
rvB46=D[vs4,u6];
rvB47=D[vs4,u7];
rvB48=D[vs4,u8];
rvB49=D[vs4,u9];
rvB410=D[vs4,u10];
rwB1=D[wB1,u1];
rwB2=D[wB1,u2];
rwB3=D[wB1,u3];
rwB4=D[wB1,u4];
rwB5=D[wB1,u5];
rwB6=D[wB1,u6];
rwB7=D[wB1,u7];
rwB8=D[wB1,u8];
rwB9=D[wB1,u9];
rwB10=D[wB1,u10];

rwB21=D[wB2,u1];
rwB22=D[wB2,u2];
rwB23=D[wB2,u3];
rwB24=D[wB2,u4];
rwB25=D[wB2,u5];
```

```
rwB26=D[wB2,u6];
rwB27=D[wB2,u7];
rwB28=D[wB2,u8];
rwB29=D[wB2,u9];
rwB210=D[wB2,u10];

rwB31=D[wB3,u1];
rwB32=D[wB3,u2];
rwB33=D[wB3,u3];
rwB34=D[wB3,u4];
rwB35=D[wB3,u5];
rwB36=D[wB3,u6];
rwB37=D[wB3,u7];
rwB38=D[wB3,u8];
rwB39=D[wB3,u9];
rwB310=D[wB3,u10];
rwB41=D[wB4,u1];
rwB42=D[wB4,u2];
rwB43=D[wB4,u3];
rwB44=D[wB4,u4];
rwB45=D[wB4,u5];
rwB46=D[wB4,u6];
rwB47=D[wB4,u7];
rwB48=D[wB4,u8];
rwB49=D[wB4,u9];
rwB410=D[wB4,u10];
xw1=xrf-a11*s1-a12*s2-a13*s3;
xw2=xrf-a11*s21+a12*s22-a13*s23;
```

```
xw3=xrr-a14*s31-a15*s32-a16*s33;

xw4=xrr-a14*s41+a15*s42-a16*s43;

moment1=Cross[F11*n3,(xw1-xrf)];

moment2=Cross[F22*n3,(xw2-xrf)];

moment3=Cross[F33*n3,(xw3-xrr)];

moment4=Cross[F44*n3,(xw4-xrr)];

springmoment1=(k*tht1)*b2;

springmoment2=(k*tht2)*b2;

springmoment3=(k*tht3)*b2;

springmoment4=(k*tht4)*b2;

dampermoment1=(c*u7)*b2;

dampermoment2=(c*u8)*b2;

dampermoment3=(c*u9)*b2;

dampermoment4=(c*u10)*b2;



F1=(-
M*g+(F11*n3)+(F22*n3)+(F33*n3)+(F44*n3)).rvA1+(moment1.rwA1)+(moment2.rwA
1)+(moment3.rwA1)+(moment4.rwA1)+(-
m*g+F11*n3).rvB1+(moment1.rwB1)+(springmoment1.rwB1)+(dampermoment1.rwB1)
+(-
m*g+F22*n3).rvB21+(moment2.rwB21)+(springmoment2.rwB21)+(dampermoment2.rw
B21)+(-
m*g+F33*n3).rvB31+(moment3.rwB31)+(springmoment3.rwB31)+(dampermoment3.rw
B31)+(-
m*g+F44*n3).rvB41+(moment4.rwB41)+(springmoment4.rwB41)+(dampermoment4.rw
B41);

F2=(-
M*g+(F11*n3)+(F22*n3)+(F33*n3)+(F44*n3)).rvA2+(moment1.rwA2)+(moment2.rwA
2)+(moment3.rwA2)+(moment4.rwA2)+(-
m*g+F11*n3).rvB2+(moment1.rwB2)+(springmoment1.rwB2)+(dampermoment1.rwB2)
+(-
m*g+F22*n3).rvB22+(moment2.rwB22)+(springmoment2.rwB22)+(dampermoment2.rw
B22)+(-
```

m*g+F33*n3).rvB32+(moment3.rwB32)+(springmoment3.rwB32)+(dampermoment3.rwB32)+(-
m*g+F44*n3).rvB42+(moment4.rwB42)+(springmoment4.rwB42)+(dampermoment4.rwB42);

F3=(-
M*g+(F11*n3)+(F22*n3)+(F33*n3)+(F44*n3)).rvA3+(moment1.rwA3)+(moment2.rwA3)+(moment3.rwA3)+(moment4.rwA3)+(-
m*g+F11*n3).rvB3+(moment1.rwB3)+(springmoment1.rwB3)+(dampermoment1.rwB3)+(-
m*g+F22*n3).rvB23+(moment2.rwB23)+(springmoment2.rwB23)+(dampermoment2.rwB23)+(-
m*g+F33*n3).rvB33+(moment3.rwB33)+(springmoment3.rwB33)+(dampermoment3.rwB33)+(-
m*g+F44*n3).rvB43+(moment4.rwB43)+(springmoment4.rwB43)+(dampermoment4.rwB43);

F4=(-
M*g+(F11*n3)+(F22*n3)+(F33*n3)+(F44*n3)).rvA4+(moment1.rwA4)+(moment2.rwA4)+(moment3.rwA4)+(moment4.rwA4)+(-
m*g+F11*n3).rvB4+(moment1.rwB4)+(springmoment1.rwB4)+(dampermoment1.rwB4)+(-
m*g+F22*n3).rvB24+(moment2.rwB24)+(springmoment2.rwB24)+(dampermoment2.rwB24)+(-
m*g+F33*n3).rvB34+(moment3.rwB34)+(springmoment3.rwB34)+(dampermoment3.rwB34)+(-
m*g+F44*n3).rvB44+(moment4.rwB44)+(springmoment4.rwB44)+(dampermoment4.rwB44);

F5=Simplify[(-
M*g+(F11*n3)+(F22*n3)+(F33*n3)+(F44*n3)).rvA4+(moment1.rwA5)+(moment2.rwA5)+(moment3.rwA5)+(moment4.rwA5)+(-
m*g+F11*n3).rvB5+(moment1.rwB5)+(springmoment1.rwB5)+(dampermoment1.rwB5)+(-
m*g+F22*n3).rvB25+(moment2.rwB25)+(springmoment2.rwB25)+(dampermoment2.rwB25)+(-
m*g+F33*n3).rvB35+(moment3.rwB35)+(springmoment3.rwB35)+(dampermoment3.rwB35)+(-
m*g+F44*n3).rvB45+(moment4.rwB45)+(springmoment4.rwB45)+(dampermoment4.rwB45)];

F6=(-
M*g+(F11*n3)+(F22*n3)+(F33*n3)+(F44*n3)).rvA6+(moment1.rwA6)+(moment2.rwA6)+(moment3.rwA6)+(moment4.rwA6)+(-
m*g+F11*n3).rvB6+(moment1.rwB6)+(springmoment1.rwB6)+(dampermoment1.rwB6)

+(-
m*g+F22*n3).rvB26+(moment2.rwB26)+(springmoment2.rwB26)+(dampermoment2.rw
B26)+(-
m*g+F33*n3).rvB36+(moment3.rwB36)+(springmoment3.rwB36)+(dampermoment3.rw
B36)+(-
m*g+F44*n3).rvB46+(moment4.rwB46)+(springmoment4.rwB46)+(dampermoment4.rw
B46);

F7=(-
M*g+(F11*n3)+(F22*n3)+(F33*n3)+(F44*n3)).rvA7+(moment1.rwA7)+(moment2.rwA
7)+(moment3.rwA7)+(moment4.rwA7)+(-
m*g+F11*n3).rvB7+(moment1.rwB7)+(springmoment1.rwB7)+(dampermoment1.rwB7)
+(-
m*g+F22*n3).rvB27+(moment2.rwB27)+(springmoment2.rwB27)+(dampermoment2.rw
B27)+(-
m*g+F33*n3).rvB37+(moment3.rwB37)+(springmoment3.rwB37)+(dampermoment3.rw
B37)+(-
m*g+F44*n3).rvB47+(moment4.rwB47)+(springmoment4.rwB47)+(dampermoment4.rw
B47);

F8=(-
M*g+(F11*n3)+(F22*n3)+(F33*n3)+(F44*n3)).rvA8+(moment1.rwA8)+(moment2.rwA
8)+(moment3.rwA8)+(moment4.rwA8)+(-
m*g+F11*n3).rvB8+(moment1.rwB8)+(springmoment1.rwB8)+(dampermoment1.rwB8)
+(-
m*g+F22*n3).rvB28+(moment2.rwB28)+(springmoment2.rwB28)+(dampermoment2.rw
B28)+(-
m*g+F33*n3).rvB38+(moment3.rwB38)+(springmoment3.rwB38)+(dampermoment3.rw
B38)+(-
m*g+F44*n3).rvB48+(moment4.rwB48)+(springmoment4.rwB48)+(dampermoment4.rw
B48);

F9=(-
M*g+(F11*n3)+(F22*n3)+(F33*n3)+(F44*n3)).rvA9+(moment1.rwA9)+(moment2.rwA
9)+(moment3.rwA9)+(moment4.rwA9)+(-
m*g+F11*n3).rvB9+(moment1.rwB9)+(springmoment1.rwB9)+(dampermoment1.rwB9)
+(-
m*g+F22*n3).rvB29+(moment2.rwB29)+(springmoment2.rwB29)+(dampermoment2.rw
B29)+(-
m*g+F33*n3).rvB39+(moment3.rwB39)+(springmoment3.rwB39)+(dampermoment3.rw
B39)+(-
m*g+F44*n3).rvB49+(moment4.rwB49)+(springmoment4.rwB49)+(dampermoment4.rw
B49);

```
F10=(-
M*g+(F11*n3)+(F22*n3)+(F33*n3)+(F44*n3)).rvA10+(moment1.rwA10)+(moment2.r
wA10)+(moment3.rwA10)+(moment4.rwA10)+(-
m*g+F11*n3).rvB10+(moment1.rwB10)+(springmoment1.rwB10)+(dampermoment1.rw
B10)+(-
m*g+F22*n3).rvB210+(moment2.rwB210)+(springmoment2.rwB210)+(dampermoment
2.rwB210)+(-
m*g+F33*n3).rvB310+(moment3.rwB310)+(springmoment3.rwB310)+(dampermoment
3.rwB310)+(-
m*g+F44*n3).rvB410+(moment4.rwB410)+(springmoment4.rwB410)+(dampermoment
4.rwB410);
```

```
(*Moment of Inertia of hull*)

Is=DiagonalMatrix[{IAx,IAy,IAz}];

Ims=DiagonalMatrix[{IAmx,IAmy,IAmz}];

FI1=(-M*aH).rvA1-(alfaH.Is).rwA1+(-m*aS1).rvB1+(-m*aS2).rvB21+(-
m*aS3).rvB31+(-m*aS4).rvB41-(alafaS1.Ims).rwB1-(alafaS2.Ims).rwB21-
(alafaS3.Ims).rwB31-(alafaS4.Ims).rwB41;

FI2=(-M*aH).rvA2-(alfaH.Is).rwA2+(-m*aS1).rvB2+(-m*aS2).rvB22+(-
m*aS3).rvB32+(-m*aS4).rvB42-(alafaS1.Ims).rwB2-(alafaS2.Ims).rwB22-
(alafaS3.Ims).rwB32-(alafaS4.Ims).rwB42;

FI3=(-M*aH).rvA3-(alfaH.Is).rwA3+(-m*aS1).rvB3+(-m*aS2).rvB23+(-
m*aS3).rvB33+(-m*aS4).rvB43-(alafaS1.Ims).rwB3-(alafaS2.Ims).rwB23-
(alafaS3.Ims).rwB33-(alafaS4.Ims).rwB43;

FI4=(-M*aH).rvA4-(alfaH.Is).rwA4+(-m*aS1).rvB4+(-m*aS2).rvB24+(-
m*aS3).rvB34+(-m*aS4).rvB44-(alafaS1.Ims).rwB4-(alafaS2.Ims).rwB24-
(alafaS3.Ims).rwB34-(alafaS4.Ims).rwB44;

FI5=(-M*aH).rvA5-(alfaH.Is).rwA5+(-m*aS1).rvB5+(-m*aS2).rvB25+(-
m*aS3).rvB35+(-m*aS4).rvB45-(alafaS1.Ims).rwB5-(alafaS2.Ims).rwB25-
(alafaS3.Ims).rwB35-(alafaS4.Ims).rwB45;

FI6=(-M*aH).rvA6-(alfaH.Is).rwA6+(-m*aS1).rvB6+(-m*aS2).rvB26+(-
m*aS3).rvB36+(-m*aS4).rvB46-(alafaS1.Ims).rwB6-(alafaS2.Ims).rwB26-
(alafaS3.Ims).rwB36-(alafaS4.Ims).rwB46;

FI7=(-M*aH).rvA7-(alfaH.Is).rwA7+(-m*aS1).rvB7+(-m*aS2).rvB27+(-
m*aS3).rvB37+(-m*aS4).rvB47-(alafaS1.Ims).rwB7-(alafaS2.Ims).rwB27-
(alafaS3.Ims).rwB37-(alafaS4.Ims).rwB47;
```

```
FI8=(-M*aH).rvA8-(alfaH.Is).rwA8+(-m*aS1).rvB8+(-m*aS2).rvB28+(-
m*aS3).rvB38+(-m*aS4).rvB48-(alafaS1.Ims).rwB8-(alafaS2.Ims).rwB28-
(alafaS3.Ims).rwB38-(alafaS4.Ims).rwB48;

FI9=(-M*aH).rvA9-(alfaH.Is).rwA9+(-m*aS1).rvB9+(-m*aS2).rvB29+(-
m*aS3).rvB39+(-m*aS4).rvB49-(alafaS1.Ims).rwB9-(alafaS2.Ims).rwB29-
(alafaS3.Ims).rwB39-(alafaS4.Ims).rwB49;

FI10=(-M*aH).rvA10-(alfaH.Is).rwA10+(-m*aS1).rvB10+(-m*aS2).rvB210+(-
m*aS3).rvB310+(-m*aS4).rvB410-(alafaS1.Ims).rwB10-(alafaS2.Ims).rwB210-
(alafaS3.Ims).rwB310-(alafaS4.Ims).rwB410;

ff1=F1+FI1;

ff2=F2+FI2;

ff3=F3+FI3;

ff4=F4+FI4;

ff5=F5+FI5;

ff6=F6+FI6;

ff7=F7+FI7;

ff8=F8+FI8;

ff9=F9+FI9;

ff10=F10+FI10;

LHSFIRSTEQUATIONCoeff1=D[ff1,D[u1,t]];

LHSFIRSTEQUATIONCoeff2=D[ff1,D[u2,t]];

LHSFIRSTEQUATIONCoeff3=D[ff1,D[u3,t]];

LHSFIRSTEQUATIONCoeff4=D[ff1,D[u4,t]];

LHSFIRSTEQUATIONCoeff5=D[ff1,D[u5,t]];

LHSFIRSTEQUATIONCoeff6=D[ff1,D[u6,t]];

LHSFIRSTEQUATIONCoeff7=D[ff1,D[u7,t]];

LHSFIRSTEQUATIONCoeff8=D[ff1,D[u8,t]];

LHSFIRSTEQUATIONCoeff9=D[ff1,D[u9,t]];

LHSFIRSTEQUATIONCoeff10=D[ff1,D[u10,t]];

firstequatRHSterm=-ff1/.{D[u1,t]->0,D[u2,t]->0,D[u3,t]->0,D[u4,t]->0,D[u5,t]-
>0,D[u6,t]->0,D[u7,t]->0,D[u8,t]->0,D[u9,t]->0,D[u10,t]->0};
```

```
LHSsecondQUATIONCoeff1=D[ff2,D[u1,t]];
LHSsecondQUATIONCoeff2=D[ff2,D[u2,t]];
LHSsecondQUATIONCoeff3=D[ff2,D[u3,t]];
LHSsecondQUATIONCoeff4=D[ff2,D[u4,t]];
LHSsecondQUATIONCoeff5=D[ff2,D[u5,t]];
LHSsecondQUATIONCoeff6=D[ff2,D[u6,t]];
LHSsecondQUATIONCoeff7=D[ff2,D[u7,t]];
LHSsecondQUATIONCoeff8=D[ff2,D[u8,t]];
LHSsecondQUATIONCoeff9=D[ff2,D[u9,t]];
LHSsecondQUATIONCoeff10=D[ff2,D[u10,t]];
secondRHSterm=-ff2/.{D[u1,t]->0,D[u2,t]->0,D[u3,t]->0,D[u4,t]->0,D[u5,t]->0,D[u6,t]->0,D[u7,t]->0,D[u8,t]->0,D[u9,t]->0,D[u10,t]->0};
LHSthirdQUATIONCoeff1=D[ff3,D[u1,t]];
LHSthirdQUATIONCoeff2=D[ff3,D[u2,t]];
LHSthirdQUATIONCoeff3=D[ff3,D[u3,t]];
LHSthirdQUATIONCoeff4=D[ff3,D[u4,t]];
LHSthirdQUATIONCoeff5=D[ff3,D[u5,t]];
LHSthirdQUATIONCoeff6=D[ff3,D[u6,t]];
LHSthirdQUATIONCoeff7=D[ff3,D[u7,t]];
LHSthirdQUATIONCoeff8=D[ff3,D[u8,t]];
LHSthirdQUATIONCoeff9=D[ff3,D[u9,t]];
LHSthirdQUATIONCoeff10=D[ff3,D[u10,t]];
thirdRHSterm=-ff3/.{D[u1,t]->0,D[u2,t]->0,D[u3,t]->0,D[u4,t]->0,D[u5,t]->0,D[u6,t]->0,D[u7,t]->0,D[u8,t]->0,D[u9,t]->0,D[u10,t]->0};
fourthQUATIONCoeff1=D[ff4,D[u1,t]];
fourthQUATIONCoeff2=D[ff4,D[u2,t]];
fourthQUATIONCoeff3=D[ff4,D[u3,t]];
fourthQUATIONCoeff4=D[ff4,D[u4,t]];
fourthQUATIONCoeff5=D[ff4,D[u5,t]];
```

fourthQUATIONCoeff6=D[ff4,D[u6,t]];

fourthQUATIONCoeff7=D[ff4,D[u7,t]];

fourthQUATIONCoeff8=D[ff4,D[u8,t]];

fourthQUATIONCoeff9=D[ff4,D[u9,t]];

fourthQUATIONCoeff10=D[ff4,D[u10,t]];

fourthRHSterm=-ff4/.{D[u1,t]->0,D[u2,t]->0,D[u3,t]->0,D[u4,t]->0,D[u5,t]->0,D[u6,t]->0,D[u7,t]->0,D[u8,t]->0,D[u9,t]->0,D[u10,t]->0};

fifthQUATIONCoeff1=D[ff5,D[u1,t]];

fifthQUATIONCoeff2=D[ff5,D[u2,t]];

fifthQUATIONCoeff3=D[ff5,D[u3,t]];

fifthQUATIONCoeff4=D[ff5,D[u4,t]];

fifthQUATIONCoeff5=D[ff5,D[u5,t]];

fifthQUATIONCoeff6=D[ff5,D[u6,t]];

fifthQUATIONCoeff7=D[ff5,D[u7,t]];

fifthQUATIONCoeff8=D[ff5,D[u8,t]];

fifthQUATIONCoeff9=D[ff5,D[u9,t]];

fifthQUATIONCoeff10=D[ff5,D[u10,t]];

fifthRHSterm=-ff5/.{D[u1,t]->0,D[u2,t]->0,D[u3,t]->0,D[u4,t]->0,D[u5,t]->0,D[u6,t]->0,D[u7,t]->0,D[u8,t]->0,D[u9,t]->0,D[u10,t]->0};

sixQUATIONCoeff1=D[ff6,D[u1,t]];

sixQUATIONCoeff2=D[ff6,D[u2,t]];

sixQUATIONCoeff3=D[ff6,D[u3,t]];

sixQUATIONCoeff4=D[ff6,D[u4,t]];

sixQUATIONCoeff5=D[ff6,D[u5,t]];

sixQUATIONCoeff6=D[ff6,D[u6,t]];

sixQUATIONCoeff7=D[ff6,D[u7,t]];

sixQUATIONCoeff8=D[ff6,D[u8,t]];

sixQUATIONCoeff9=D[ff6,D[u9,t]];

sixQUATIONCoeff10=D[ff6,D[u10,t]];

```
sixRHSthterm=-ff6/.{D[u1,t]->0,D[u2,t]->0,D[u3,t]->0,D[u4,t]->0,D[u5,t]->0,D[u6,t]->0,D[u7,t]->0,D[u8,t]->0,D[u9,t]->0,D[u10,t]->0};

sevenQUATIONCoeff1=D[ff7,D[u1,t]];

sevenQUATIONCoeff2=D[ff7,D[u2,t]];

sevenQUATIONCoeff3=D[ff7,D[u3,t]];

sevenQUATIONCoeff4=D[ff7,D[u4,t]];

sevenQUATIONCoeff5=D[ff7,D[u5,t]];

sevenQUATIONCoeff6=D[ff7,D[u6,t]];

sevenQUATIONCoeff7=D[ff7,D[u7,t]];

sevenQUATIONCoeff8=D[ff7,D[u8,t]];

sevenQUATIONCoeff9=D[ff7,D[u9,t]];

sevenQUATIONCoeff10=D[ff7,D[u10,t]];

sevenRHSthterm=-ff7/.{D[u1,t]->0,D[u2,t]->0,D[u3,t]->0,D[u4,t]->0,D[u5,t]->0,D[u6,t]->0,D[u7,t]->0,D[u8,t]->0,D[u9,t]->0,D[u10,t]->0};

EIGHTQUATIONCoeff1=D[ff8,D[u1,t]];

EIGHTQUATIONCoeff2=D[ff8,D[u2,t]];

EIGHTQUATIONCoeff3=D[ff8,D[u3,t]];

EIGHTQUATIONCoeff4=D[ff8,D[u4,t]];

EIGHTQUATIONCoeff5=D[ff8,D[u5,t]];

EIGHTQUATIONCoeff6=D[ff8,D[u6,t]];

EIGHTQUATIONCoeff7=D[ff8,D[u7,t]];

EIGHTQUATIONCoeff8=D[ff8,D[u8,t]];

EIGHTQUATIONCoeff9=D[ff8,D[u9,t]];

EIGHTQUATIONCoeff10=D[ff8,D[u10,t]];

{

 {EIGHTRHSthterm=-ff8/.{D[u1,t]->0,D[u2,t]->0,D[u3,t]->0,D[u4,t]->0,D[u5,t]->0,D[u6,t]->0,D[u7,t]->0,D[u8,t]->0,D[u9,t]->0,D[u10,t]->0};},

 {⍰}

}
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NINEQUATIONCoeff1=D[ff9,D[u1,t]];

NINEQUATIONCoeff2=D[ff9,D[u2,t]];

NINEQUATIONCoeff3=D[ff9,D[u3,t]];

NINEQUATIONCoeff4=D[ff9,D[u4,t]];

NINEQUATIONCoeff5=D[ff9,D[u5,t]];

NINEQUATIONCoeff6=D[ff9,D[u6,t]];

NINEQUATIONCoeff7=D[ff9,D[u7,t]];

NINEQUATIONCoeff8=D[ff9,D[u8,t]];

NINEQUATIONCoeff9=D[ff9,D[u9,t]];

NINEQUATIONCoeff10=D[ff9,D[u10,t]];

NINERHSthterm=-ff9/.{D[u1,t]->0,D[u2,t]->0,D[u3,t]->0,D[u4,t]->0,D[u5,t]-
>0,D[u6,t]->0,D[u7,t]->0,D[u8,t]->0,D[u9,t]->0,D[u10,t]->0};

TENQUATIONCoeff1=D[ff10,D[u1,t]];

TENQUATIONCoeff2=D[ff10,D[u2,t]];

TENQUATIONCoeff3=D[ff10,D[u3,t]];

TENQUATIONCoeff4=D[ff10,D[u4,t]];

TENQUATIONCoeff5=D[ff10,D[u5,t]];

TENQUATIONCoeff6=D[ff10,D[u6,t]];

TENQUATIONCoeff7=D[ff10,D[u7,t]];

TENQUATIONCoeff8=D[ff10,D[u8,t]];

TENQUATIONCoeff9=D[ff10,D[u9,t]];

TENQUATIONCoeff10=D[ff10,D[u10,t]];

TENRHSthterm=-ff10/.{D[u1,t]->0,D[u2,t]->0,D[u3,t]->0,D[u4,t]->0,D[u5,t]-
>0,D[u6,t]->0,D[u7,t]->0,D[u8,t]->0,D[u9,t]->0,D[u10,t]->0};

Import[StringJoin[NotebookDirectory[],"ToMatlab.m"]]

matlabReplacements={xt->x,yt->y,zt->z,tht->th, phit->phi, psit->psi,tht1->th1,tht2-
>th2,tht3->th3,tht4->th4,u1->v1,u2->v2,u3->v3,u4->w4,u5->w5,u6->w6,u7->w7,u8-
>w8,u9->w9,u10->w10,D[u1,t]->du1,D[u2,t]->du2,D[u3,t]->du3,D[u4,t]->du4,D[u5,t]-
>du5,D[u6,t]->du6,D[u7,t]->du7,D[u8,t]->du8,D[u9,t]->du9,D[u10,t]->du10};

LHS=ToMatlab[{
```

{LHSFIRSTEQUATIONCoeff1,LHSFIRSTEQUATIONCoeff2,LHSFIRSTEQUATIONCoeff3,LHSFIRSTEQUATIONCoeff4,LHSFIRSTEQUATIONCoeff5,LHSFIRSTEQUATIONCoeff6,LHSFIRSTEQUATIONCoeff7,LHSFIRSTEQUATIONCoeff8,LHSFIRSTEQUATIONCoeff9,LHSFIRSTEQUATIONCoeff10},{LHSsecondQUATIONCoeff1,LHSsecondQUATIONCoeff2,LHSsecondQUATIONCoeff3,LHSsecondQUATIONCoeff4,LHSsecondQUATIONCoeff5,LHSsecondQUATIONCoeff6,LHSsecondQUATIONCoeff7,LHSsecondQUATIONCoeff8,LHSsecondQUATIONCoeff9,LHSsecondQUATIONCoeff10},

{LHSthirdQUATIONCoeff1,LHSthirdQUATIONCoeff2,LHSthirdQUATIONCoeff3,LHSthirdQUATIONCoeff4,LHSthirdQUATIONCoeff5,LHSthirdQUATIONCoeff6,LHSthirdQUATIONCoeff7,LHSthirdQUATIONCoeff8,LHSthirdQUATIONCoeff9,LHSthirdQUATIONCoeff10},{fourthQUATIONCoeff1,fourthQUATIONCoeff2,fourthQUATIONCoeff3,fourthQUATIONCoeff4,fourthQUATIONCoeff5,fourthQUATIONCoeff6,fourthQUATIONCoeff7,fourthQUATIONCoeff8,fourthQUATIONCoeff9,fourthQUATIONCoeff10},

{fifthQUATIONCoeff1,fifthQUATIONCoeff2,fifthQUATIONCoeff3,fifthQUATIONCoeff4,fifthQUATIONCoeff5,fifthQUATIONCoeff6,fifthQUATIONCoeff7,fifthQUATIONCoeff8,fifthQUATIONCoeff9,fifthQUATIONCoeff10},

{sixQUATIONCoeff1,sixQUATIONCoeff2,sixQUATIONCoeff3,sixQUATIONCoeff4,sixQUATIONCoeff5,sixQUATIONCoeff6,sixQUATIONCoeff7,sixQUATIONCoeff8,sixQUATIONCoeff9,sixQUATIONCoeff10},

{sevenQUATIONCoeff1,sevenQUATIONCoeff2,sevenQUATIONCoeff3,sevenQUATIONCoeff4,sevenQUATIONCoeff5,sevenQUATIONCoeff6,sevenQUATIONCoeff7,sevenQUATIONCoeff8,sevenQUATIONCoeff9,sevenQUATIONCoeff10},{EIGHTQUATIONCoeff1,EIGHTQUATIONCoeff2,EIGHTQUATIONCoeff3,EIGHTQUATIONCoeff4,EIGHTQUATIONCoeff5,EIGHTQUATIONCoeff6,EIGHTQUATIONCoeff7,EIGHTQUATIONCoeff8,EIGHTQUATIONCoeff9,EIGHTQUATIONCoeff10},{NINEQUATIONCoeff1,NINEQUATIONCoeff2,NINEQUATIONCoeff3,NINEQUATIONCoeff4,NINEQUATIONCoeff5,NINEQUATIONCoeff6,NINEQUATIONCoeff7,NINEQUATIONCoeff8,NINEQUATIONCoeff9,NINEQUATIONCoeff10},{TENQUATIONCoeff1,TENQUATIONCoeff2,TENQUATIONCoeff3,TENQUATIONCoeff4,TENQUATIONCoeff5,TENQUATIONCoeff6,TENQUATIONCoeff7,TENQUATIONCoeff8,TENQUATIONCoeff9,TENQUATIONCoeff10}}/. matlabReplacements] ;

LHS1=ToMatlab[{LHSFIRSTEQUATIONCoeff1,LHSFIRSTEQUATIONCoeff2,LHSFIRSTEQUATIONCoeff3,LHSFIRSTEQUATIONCoeff4,LHSFIRSTEQUATIONCoeff5, LHSFIRSTEQUATIONCoeff6,LHSFIRSTEQUATIONCoeff7,LHSFIRSTEQUATIONCoeff8,LHSFIRSTEQUATIONCoeff9,LHSFIRSTEQUATIONCoeff10}/. matlabReplacements];

LHS2=ToMatlab[{LHSsecondQUATIONCoeff1,LHSsecondQUATIONCoeff2,LHSsecondQUATIONCoeff3,LHSsecondQUATIONCoeff4,LHSsecondQUATIONCoeff5,LHSsecondQUATIONCoeff6,LHSsecondQUATIONCoeff7,LHSsecondQUATIONCoeff8,LHSsecondQUATIONCoeff9,LHSsecondQUATIONCoeff10}/. matlabReplacements];

LHS3=ToMatlab[{LHSthirdQUATIONCoeff1,LHSthirdQUATIONCoeff2,LHSthirdQUATIONCoeff3,LHSthirdQUATIONCoeff4,LHSthirdQUATIONCoeff5,LHSthirdQUATIONCoeff6,LHSthirdQUATIONCoeff7,LHSthirdQUATIONCoeff8,LHSthirdQUATIONCoeff9,LHSthirdQUATIONCoeff10}/. matlabReplacements];

LHS4=ToMatlab[{fourthQUATIONCoeff1,fourthQUATIONCoeff2,fourthQUATIONCoeff3,fourthQUATIONCoeff4,fourthQUATIONCoeff5,fourthQUATIONCoeff6,fourthQUATIONCoeff7,fourthQUATIONCoeff8,fourthQUATIONCoeff9,fourthQUATIONCoeff10}/. matlabReplacements];

LHS5=ToMatlab[{fifthQUATIONCoeff1,fifthQUATIONCoeff2,fifthQUATIONCoeff3,fifthQUATIONCoeff4,fifthQUATIONCoeff5,fifthQUATIONCoeff6,fifthQUATIONCoeff7,fifthQUATIONCoeff8,fifthQUATIONCoeff9,fifthQUATIONCoeff10}/. matlabReplacements];

LHS6=ToMatlab[{sixQUATIONCoeff1,sixQUATIONCoeff2,sixQUATIONCoeff3,sixQUATIONCoeff4,sixQUATIONCoeff5,sixQUATIONCoeff6,sixQUATIONCoeff7,sixQUATIONCoeff8,sixQUATIONCoeff9,sixQUATIONCoeff10}/. matlabReplacements];

LHS7=ToMatlab[{sevenQUATIONCoeff1,sevenQUATIONCoeff2,sevenQUATIONCoeff3,sevenQUATIONCoeff4,sevenQUATIONCoeff5,sevenQUATIONCoeff6,sevenQUATIONCoeff7,sevenQUATIONCoeff8,sevenQUATIONCoeff9,sevenQUATIONCoeff10}/. matlabReplacements];

LHS8=ToMatlab[{EIGHTQUATIONCoeff1,EIGHTQUATIONCoeff2,EIGHTQUATIONCoeff3,EIGHTQUATIONCoeff4,EIGHTQUATIONCoeff5,EIGHTQUATIONCoeff6,EIGHTQUATIONCoeff7,EIGHTQUATIONCoeff8,EIGHTQUATIONCoeff9,EIGHTQUATIONCoeff10}/. matlabReplacements];

LHS9=ToMatlab[{NINEQUATIONCoeff1,NINEQUATIONCoeff2,NINEQUATIONCoeff3,NINEQUATIONCoeff4,NINEQUATIONCoeff5,NINEQUATIONCoeff6,NINEQUATIONCoeff7,NINEQUATIONCoeff8,NINEQUATIONCoeff9,NINEQUATIONCoeff10}/. matlabReplacements];

LHS10=ToMatlab[{TENQUATIONCoeff1,TENQUATIONCoeff2,TENQUATIONCoeff3,TENQUATIONCoeff4,TENQUATIONCoeff5,TENQUATIONCoeff6,TENQUATIONCoeff7,TENQUATIONCoeff8,TENQUATIONCoeff9,TENQUATIONCoeff10}/. matlabReplacements];

```
RHS=ToMatlab[{ firstequatRHSterm,secondRHSterm,
thirdRHSterm,fourthRHSterm,fifthRHSterm,sixRHSthterm,sevenRHSthterm,EIGHTRHSthterm,NINERHSthterm,TENRHSthterm}  /. matlabReplacements] ;

rhs1=ToMatlab[{  firstequatRHSterm}/. matlabReplacements];

rhs2=ToMatlab[{ secondRHSterm}/. matlabReplacements];

rhs3=ToMatlab[{ thirdRHSterm}/. matlabReplacements];

rhs4=ToMatlab[{ fourthRHSterm}/. matlabReplacements];

rhs5=ToMatlab[{ fifthRHSterm}/. matlabReplacements];

rhs6=ToMatlab[{sixRHSthterm}/. matlabReplacements];

rhs7=ToMatlab[{sevenRHSthterm}/. matlabReplacements];

rhs8=ToMatlab[{EIGHTRHSthterm}/. matlabReplacements];

rhs9=ToMatlab[{NINERHSthterm}/. matlabReplacements];

rhs10=ToMatlab[{TENRHSthterm}/. matlabReplacements];

SetDirectory[NotebookDirectory[]];

<<ToMATLAB.m

ToMatlab[LHS];

ToMatlab[RHS];

Dictionary[];

f=OpenWrite["Lefteko.m"];

WriteMatlab[LHS,f,"LHS"];

Close f;

d=OpenWrite["Righteko.m"];

WriteMatlab[RHS,d,"RHS"];

Close d;
```

9 Vita

Mohamed Amer was born April 10, 1983 in Saudi Arabia, He earned his bachelor's degree in mechanical engineering in 2005 from MTC in Egypt. He worked as research assistant until 2009. He received a Master of Science Degree in Mechanical Engineering in 2011 from MTC Cairo, Egypt. In 2017 he continued his studies as a PhD student in Lehigh university in USA in the major of Mechanical Engineering. He is awarded his Degree in 2020.